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TECHNICAL REPORT

Acute Effects of Irradiation on People and Animals from Soviet Underground Nuclear Explosions

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September 2007

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14. ABSTRACT

We studied the mechanisms and features of the formation of the response reactions in humans and in animals to the effects of radiation factors imposed on them from experimental nuclear explosions. It was established that, as a result of short-term exposure of testing participants and the populace to a low-lying radioactive nuclear explosion cloud in 1968, with an overall external gamma irradiation of from 170 to 260 mGy (17.0 to 26.0 rad), and an internal contamination from freshly produced radioactive fission products in the 296 to 740 MBq (8 to 20 mCi) range, radiation reactions were expressed to varying degrees. Clinical manifestations of radiation reactions were accompanied by hematological changes and central nervous system damage.

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CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI units of measurement)

MULTIPLY TO GET	BY BY	TO GET DIVIDE
angstrom	1.000 000 x E-10	meters (m)
atmosphere	1.012 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E + 2	kilo pascal (kPa)
barn	1.000 x E – 28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 x E + 3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical)/cm^2	4.184 000 x E-2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 x E + 1	giga becquerel (GBq)*
degree (angle)	1.745 329 x E – 2	radian (rad)
degree (Fahrenheit)	Tk = (t +459.69)/1.8	degree kelvin (K)
electron volt	1.602 19 x E – 19	joule (J)
erg	1.000 000 x E – 7	joule (J)
erg/sec	1.000 000 x E – 7	watt (W)
foot	3.048 000 x X-1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E – 3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E + 9	joule (J)
joule/kilogram (J/kg) (absorbed dose)	1.000 000	Gray (Gy)**
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E + 3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E – 6	meter (m)
mil	2.540 000 x E – 5	meter (m)
mile (international)	1.609 344 x E + 3	meter (m)
ounce	2.834 952 x E – 2	kilogram (kg)
pound-force (lbf avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E – 1	newton-meter (N*m)
pound-force/inch	1.751 268 x E + 2	newton-meter (N/m)
pound-force/foot^2	4.788 026 x E – 2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E – 2	kilogram-meter^2 (kg*m^2)
pound-mass/foot^3	1.601 846 x E + 1	kilogram/m^3 (kg/m^3)
rad (radiation absorbed dose)	1.000 000 x E – 2	Gray (Gy) **
rem (roentgen equivalent man)		Sievert (Sv) ***
roentgen	2.579 760 x E – 4	coulomb/kilogram (C/kg)
shake	1.000 000 x E – 8	second (s)
Slug	1.459 390 x E + 1	kilogram (kg)
Torr (mm Hg, 0 degrees C)	1.333 22 x E – 1	kilo pascal (kPa)

* *The Becquerel (Bq) is the SI unit of radioactivity: 1 Bq = 1 event/s.*

** *The Gray (Gy) is the SI unit of absorbed radiation.*

*** *The Sievert (Sv) is the SI unit of dose equivalent.*

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ABSTRACT

We studied the mechanisms and features of the formation of the response reactions in humans and in animals to the effects of radiation factors imposed on them from experimental nuclear explosions. It was established that, as a result of short-term exposure of testing participants and the populace to a low-lying radioactive nuclear explosion cloud in 1968, with an overall external gamma irradiation of from 170 to 260 mGy (17.0 to 26.0 rad), and an internal contamination from freshly produced radioactive fission products in the 296 to 740 MBq (8 to 20 mCi) range, radiation reactions were expressed to varying degrees. Clinical manifestations of radiation reactions were accompanied by hematological changes and central nervous system damage. In experiments on animals with adequate irradiation conditions, the results obtained also confirmed the high biological effectiveness of the combined effects of inhaled freshly produced fission products with external gamma irradiation.

In 1957 the USSR Ministry of Public Health created two clinics for systematic observation of the radiation situation and state of health of the residents of the contaminated regions. Each clinic had clinical, biophysical, and other laboratories set up. Clinic 4, located in Semipalatinsk, was assigned to study and evaluate the radiation and hygienic situation in the regions adjoining the Semipalatinsk test range, evaluate the impact of the nuclear testing on public health, and conduct research and practical work on questions of public safety. It was supervised by the Institute of Biophysics. Owing to secrecy and security reasons, its mission was not publicized, and it actually operated under the name, "Antibrucellosis Clinic No. 4 of the USSR Ministry of Public Health" for several years. After the independence of Kazakhstan in 1991, the clinic became a specialized institute the following year. It is now called the "Kazakh Scientific-Research Institute of Radiation Medicine and Ecology".

Many of the records accumulated by Clinic 4 physically remained in the Institute after independence, though some went to the Russian Federation. With the end of the Cold War, and the loosening of security and classification restrictions, scientists and physicians in Kazakhstan, Russia, and Ukraine were now able to publish their work for the public good. Accordingly the Defense Nuclear Agency was able to contract with the Institute to review, analyze, and now finally publish this particular study, among others. It is felt that this important work, on some of the medical and biological effects created by nuclear underground explosions, will improve our understanding of these subjects and contribute significantly to consequence management and medical efforts, should a major radiological incident ever occur in the future.

It should be stressed that this document, including the collection, presentation, and conclusions derived from the data presented in this document are entirely the work of the authors. The Defense Threat Reduction Agency (DTRA) and its predecessor agencies did not collaborate in the analysis of data nor the preparation of the report, aside from correction of grammatical structure and syntax plus updating radiation units to SI units. Editorial changes were carefully made in order not to alter the scientific content of the document, only its format and presentability. Consequently, the findings and opinions expressed in this document are entirely those of the authors and do not represent those of DTRA, the Department of Defense, or the U.S. Government.

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ERRATA

Gusev BI, Kurakina NN, Strelnikov AV (2007) Acute Effects of Irradiation on People and Animals from Soviet Underground Nuclear Explosions. Technical Report DTRA-TR-07-39. Fort Belvoir, VA: Defense Threat Reduction Agency.

A previous document posted at this link stated in the Table of Contents and on page 18 that data cited in the report were obtained from an underground test conducted January 7, 1968. This date is incorrect. It is most likely that these data were obtained after the test of May 31, 1974 instead, although this cannot be verified. The phrase “Radiation Situation after Test” has replaced “Test of January 7, 1968” at these two locations in the document. The editor apologizes for this error.

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ACUTE EFFECTS OF IRRADIATION ON PEOPLE AND ANIMALS FROM SOVIET UNDERGROUND NUCLEAR EXPLOSIONS

INTRODUCTION

The literature on radiobiology is widespread and considers in detail the issues concerning acute radiation reactions, including acute radiation illness in humans and animals. The conventional opinion is that the radiation reactions of biological subjects depend on the amounts of the effective and absorbed doses. Detailed studies of acute radiation illness in humans and in animals, both from gamma-neutron irradiation and from high-dose internal irradiation of the body, have been performed. All these materials indicate the presence of a specific range of doses; the degree of expression and the severity of the radiation reactions of biological subjects and humans depend on the level of these doses.

The problem of combined radiation injuries, especially with confirmation of the results of clinical observations through experimental research on animals subjected to similar radiation effects, has not been solved in practice. Some nations in the nuclear club conducted similar work during nuclear weapons tests, which was necessitated by emergency situations, but these results were classified for a specified period of time. Within the last three years, some of these materials have become public property or owned by professionals. The opportunity has arisen to analyze and interpret the materials dedicated to the problems of the injury-provoking effects of freshly produced nuclear explosion fission products being inhaled in combination with external gamma irradiation of the body. Of great interest in this regard are those works which analyze the features of the clinical course of combined radiation injuries (V.G. Ryadov, I.Ya. Vasilenko, 1966; V.G. Ilyin, 1966; A.T. Ivannikov, A.I. Gushchin, 1966; A.T. Ivannikov, 1966; B.I. Gusev, L.M. Ponomaryov, 1969; L.K. Tikhomirova and co-authors, 1987; Koznova and co-authors, 1987; N.G. Darenskaya and co-authors, 1987).

The purpose of this report is to familiarize the readers with the materials on combined radiation injuries to humans and large laboratory animals affected by radiation factors from an underground nuclear explosion. Figure 1 details the Semipalatinsk Nuclear Test site area in the Central Asian Republics.

Figure 1. Map of the Semipalatinsk Nuclear Test Site in the Central Asian Republics.

MATERIALS AND METHODS OF RESEARCH

Test of January 15, 1965

On January 15, 1965, at the confluence of the Ashisu and Chagan Rivers (Semipalatinsk Oblast), a thermonuclear device with a yield of roughly 100 to 140 kt was detonated at a scaled depth of 41 m/kt$^{1/3.4}$ (Ref. 4).[1] The purpose of this explosion was to create an artificial reservoir. As a result of the excavation of the ground, a radioactive cloud was formed that rose to an altitude of up to 4.5 km, and a crater was formed with a diameter of 408 m, and a depth of 100 m. The height of the piled-up soil was 42 m, and the width was 412 m. The velocity of the cloud was 40 km/hr. One must note that the populace of Sarapan and Isa was evacuated to Znamenka settlement for 96 hours. After that, they were returned.

After the explosion on the Chagan River, we took measurements of the levels of gamma irradiation on the open territory and in enclosed areas along the territory of the radioactive track. The passage of the radioactive cloud and the formation of a track were traced to a distance of 100 km from the explosion location.

Generalization of the measurement results obtained in the given experiment and in a series of similar work in which we participated permitted us to calculate the values of the coefficient of protection provided by residential buildings made of various construction materials used in the study region against irradiation as the radioactive cloud passed over, and against irradiation from radioactive fallout onto the locale. The average values for protection coefficients provided by several types of buildings are shown in Table 1.

As illustrated in Table 1, the values of the protection coefficients of buildings against radioactive fallout in the locale depend not only on the quality of the construction material, but also on which story of the building one is located. The maximum protection coefficient was provided by basement rooms. Of the one-story buildings, the maximum coefficient of protection was provided by those made of adobe. The protection provided by buildings during the passage of the radioactive cloud is an average of five (5) times lower than that provided against radioactive fallout.

1 Scaled depth (or negative height = distance of exploded device from surface, in meters, divided by the cube root [actually, 3.4] of the yield, in kilotons TNT equivalent).

Table 1. Average coefficients of protection of buildings against radioactive irradiation from an explosion cloud and against local radioactive fallout.

Types of Residential Buildings	# of Measurements	Against Fallout	Against the Cloud
Single-story brick	9	10	--
Two-story brick: 1st story 2nd story	 18 18	 17 15	 -- 3.15
Single-story wooden	12	8.7	1.8
Two-story wooden: Basement 1st story 2nd story	 9 9 9	 30 12 8	 -- -- --
Single-story adobe	31	13	3.2
Household adobe additions	12	6.3	1.12

After the underground nuclear explosion, radioactive gasses leaked out of the crater for several days. It was established that the doses of external irradiation caused by the effects of the radioactive gas streams reached considerable values outside the zone of the radioactive track. When the gas stream passes through population points, we observe the effect of sorption of radioactive materials on the surfaces of rooms and all contents. Given this condition, ventilating the rooms has practically no effect on reducing the gamma background level. Clothing is contaminated, especially fur clothing and hair. It was established that a reduction in the level of gamma radiation occurs by a power function with a power index n = -3.

The significance of radioactive fallout on the locale as a source of external irradiation is determined by the quantity of radioactive precipitates and their isotopic composition. An experimental study of the dose rate dynamics along the path of the radioactive cloud in this given explosion indicated that a reduction in the dose rate over time occurs by a power function with an average power index equal to -1.96.

Such a relatively rapid drop in dose rate is caused by the presence in the precipitates of mostly short-lived isotopes of induced activity. The duration of the effect on humans of radioactive fallout at a distance of 100 km from the epicenter was 10 days; at a distance of 40 km it was two months; and at a distance of 15 km from the explosion location in a more contamination populated point, it was one year. After that time, the contribution of fallout to the external irradiation dose was insignificant. Thus, the time factors played an important role in the formation of the irradiation dose for humans. From the actual conditions in the track of the radioactive cloud, according to our calculations, the gamma irradiation doses for the open locale are characterized by the following values (Table 2).

Initial data:

q = 140.00 kt;

V = 40.0 km/hr

Znamenka - dose rate at zero hour +50 hours = 11.8 mR/hr

Sarapan - dose rate at zero hour +96 hours (time when population returned) = 11.5 mR/hr

Isa - dose rate at zero hour +96 hours (time when population returned) = 8.0 mR/hr.

By our methods, we calculated the dose to the thyroid gland from radioactive iodines, to the entire body from Cs-137, and to bone tissue from Sr-90. The dose from inhalation for the adult population for all was identical, since the entire population was located in Znamenka at the time the cloud passed (calculated). Calculations were on the "standard" individual (weight = 70 kg, age $\geq$ 20 yrs, weight of thyroid gland = 0.02 kg, rate of lung ventilation = 30 l/min, weight of skeleton minus marrow = 7.0 kg).

Table 2. Calculated parameters of the radiation situation in population points.

	Sarapan	**Isa**	**Znamenka**
Distance from explosion epicenter, km	15	35	40
Dose rate at zero hr +24, R/hr	0.174	0.121	0.05
Time of arrival of cloud, hr	0.375	0.875	1.00
Time of irradiation from the cloud, hr	0.38	0.54	0.58
Time of conditional completion of irradiation from the cloud, hr	0.76	1.42	1.58
Dose from the cloud, mGy	73.3	33.9	13.2
Dose from fallout, mGy	373	294	123
Dose to the population, mGy	158*	135*	108

**- with regard to the dose, obtained in Znamenka after 4 days.*

The total dose from all iodine isotopes to the thyroid gland was 22.3 mGy.
The dose from strontium-90 to the skeleton was 1.06 mGy.
The dose from cesium-137 to the whole body was 15.4 mGy.

As a result of the fallout of radioactive matter, not only was the surface of the territory contaminated, but also all animal raw feed reserves which were located in the territory. Considering the season during which the explosion was conducted, when the dairy cattle were kept in stalls, contamination of the milk via radioactive materials was determined by their content in the fodder.

The main pathway for radioactive matter to enter the human body during the first few months was migration along the "fodder-animal-human" food chain. The contribution of radioactive isotopes in the food rations of humans was insignificant, since cattle are not slaughtered during the winter, and meat which is eaten had already been prepared earlier in each individual household. The doses obtained by the populace from using contaminated milk were calculated according to the results of laboratory testing of milk samples taken in Sarapan, Isa and Znamenka (Table 3).

Table 3. Total dose to the thyroid gland from inhalation and oral (via milk) ingestion depending on age, mSv.

Population Points	**Age, years**								
	7	8	9	10	11	12	12	14	Adults
Sarapan	36.2	33.6	31.8	30.0	27.6	25.4	23.7	22.2	21.5
Isa	40.5	37.4	35.1	33.0	30.4	28.0	26.0	24.3	22.0
Znamenka	55.5	50.5	46.7	42.8	39.3	36.2	33.5	31.3	26.1

The irradiation doses to the whole body, bone and the effective dose for the adult population from inhalation and oral (via milk) ingestion of radionuclides is shown in Table 4.

Table 4. Irradiation doses to the whole body, bone, and effective dose for the adult population.

Dose, mSv	Population Points		
	Sarapan	**Isa**	**Znamenka**
Whole body dose (Cs-137)	19.3	22.8	18.9
Dose to skeleton (Sr-90)	1.98	2.78	1.92
Total equivalent dose	177.3	157.8	126.9

Before the experiment (from January 2 to January 12, 1965), a portion of the population of neighboring villages, as well as test participants, underwent preliminary medical examination. The medical examination included 175 male test participants ranging in age from 20 to 40 years and 160 males from nearby settlements of the same age group. The average age of those examined was 28.5 years. During the first eight days after the experiment, 310 people from the above-noted group (160 participants and 150 residents) underwent a second examination of the same scope and with the same paraclinical methods as before the irradiation. A third medical examination was conducted 30-60 days after the experiment (275 people, of whom 140 were military, and 135 were residents of neighboring villages) (Table 5).

Table 5. Numbers in groups studied (absolute numbers).

Research contingents	1965			1974	
	Pre-irradiation	1-8 days post exposure	30-60 days post exposure	1-3 days post exposure	30-60 days post exposure
20-40 yrs	335	310	275	155	145

Test of May 31, 1974

In May of 1974, a subsequent underground nuclear explosion was conducted at the Semipalatinsk nuclear test site. The initial data are as follows:

q = 150.00 kt

V = 45.0 km/hr

$h_{\text{depth of burial}}$ = 450 m

Two hours after the explosion, a venting to the surface occurred and a radioactive cloud formed. The surface and air tracking services which followed the passage of the cloud recorded the following parameters (Table 6).

Table 6. Calculated parameters of the radiation situation in population points.

Parameters	Sarapan	Isa
Distance from explosion epicenter, km	20	30
Dose rate at zero hr +24, R/hr	0.072	0.055
Time of arrival of cloud, hr	0.44	0.67
Time of irradiation from the cloud, hr	0.39	0.45
Time of conditional completion of irradiation from the cloud, hr	0.82	1.12
Dose from the cloud, mGy	27.4	17.1
Dose from fallout, mGy	157	127
Dose to the population, mGy	148	115

The cloud passed above the populated points of Sarapan and Isa at an altitude of 1.0 km.

The dose rate in Sarapan one hour after the venting was 3.26 R/hr.

The dose rate in Isa (Chinzhi) two hours after the venting was 1.09 R/hr.

Given these explosion parameter data and the data from the radiation survey, we calculated the parameters of the radiation survey according to our methods. The doses from inhalation to the thyroid gland (iodine-131, 133, 135), to bone tissue (strontium-90) and to the whole body (cesium-137) were determined by calculation (Table 7).

Table 7. Doses to the thyroid gland from inhalation depending on age, mGy.

Populated Points	Age, years								
	7	8	9	10	11	12	13	14	Adults
Sarapan	52.1	50.3	48.7	47.2	43.4	40.2	37.5	35.2	50.6
Isa	58.7	56.5	54.8	53.1	48.8	45.3	42.2	39.5	56.9

The doses of whole body irradiation and of the bone tissue and total equivalent dose for the adult population for inhalation of radionuclides are shown in Table 8.

Over a period of 1-3 days, 155 males, 20-40 years in age, underwent medical examination, of the same scope and according to the same paraclinical methods as did the group irradiated in 1965. Thirty to sixty days afterward, 146 people from the irradiated groups underwent a secondary medical examination.

The results from analyzing the medical research conducted on the group of 335 individuals, before the beginning of the thermonuclear explosion on January 15, 1965, were used as the control data for evaluating acute irradiation effects.

Table 8. Doses of whole body irradiation and of the bone tissue and total equivalent dose for the adult population.

Dose, mSv	Population Point	
	Sarapan	Isa
Whole body dose (Cs-137)	34.9	49.2
Dose to skeleton (Sr-90)	1.62	2.31
Total equivalent dose	183	164

The purpose of the research was to evaluate the reactions of the central nervous system, of the blood vessels, and of the circulating blood of the individuals who were subjected to acute effects of external irradiation and internal contamination via radioactive fission products of the cloud from the underground nuclear explosion. Considering the technical capabilities of the time, the most simple and informative clinical and paraclinical methods were selected to permit the fulfillment of the set objectives in the screening process. During the irradiation period (initial period), for a rather representative group of young males (close to 2,000 individuals) from 20-40 years of age, we analyzed the circulating blood indices, having used this later as the norm for residents of the Semipalatinsk Region (Table 9).

Table 9. Peripheral blood indices in controls.

Index	Sex	Average	Normal Range Values
Erythrocytes, 10^{12}/l	Male Female	4.6 4.2	4.0 – 5.1 3.7 – 4.7
Hemoglobin, g/l	Male Female	148 130	130 165
Color index	*	0.93	0.82 – 1.05
ESR, mm/h	Male Female	5.0 9.0	1.0 – 10.0 2.0 – 15.0
Thrombocytes, 10^9/l	*	250	180 – 320
Leukocytes, 10^9/l	*	6.4	4.0 – 8.8
-neutrophils, segmented, %	*	58.0	44 – 72
-neutrophils, band, %	*	3.5	1 – 6
-eosinophils, %	*	3.0	0 – 5
-basophils, %	*	0.5	0 – 1
-lymphocytes, %	*	28.5	17 – 40
-monocytes, %	*	6.0	2 - 9

*Note: * - index has no sex difference.*

Research Methods

Taste

In order to research the functions of the taste analyzer, we used the widely employed drop method. We used four taste stimuli:

- Sweet - a solution of sugar in concentrations of 0.25%, 0.5%, 1%, 1.5%, 2%, 3%, and 4%;
- Salty - a solution of table salt in the same concentrations as the sugar solution;
- Sour - a solution of salty acid in the same concentrations as the sugar solution; and
- Bitter - a solution of quinine in concentrations of 0.0005%, 0.001%, 0.002%, 0.003%, 0.004%, 0.005%, and 0.006%.

After rinsing the mouth cavity with distilled water, 3-4 drops of a 0.25% water solution of sugar was dripped onto the tip of the tongue. The study subject was asked to determine the taste stimulus without closing the mouth. If the taste stimulus was not guessed, the study subject rinsed his mouth and after 2 to 3 minutes (to prevent adaptation), a solution of sugar was dripped onto the tip of the tongue, in the next higher concentration and so forth until the taste stimulus was determined. The following methods were used to determine the thresholds for perceiving a taste sensation: for salty and sour (solutions were dripped onto the surface on both sides of the tongue), and for bitter, the solution was dripped onto the back of the tongue. We kept a gap of 5-6 minutes between determining the taste stimuli.

Thus, using the drop method we determined the thresholds for perceiving taste stimuli and recorded the misinterpretation of taste stimuli at the sub-threshold concentrations.

We considered the following concentrations as the normal thresholds for perceiving taste stimuli: sweet 0.5 - 2%; salty and sour 0.25 - 1.5%; bitter 0.001-0.003%. We must note that our data do not differ from the standards found in the literature (M.A. Khodyreva, 1957).

Olfactory

To research the olfactory analyzer, we used the Elsberg and Levi method (C. Elsberg, J. Levi, 1956). We determined the olfactory threshold, the adaptation time, and the restoration time using four stimuli: rosemary, thymol, camphor and tar. Rosemary is a substance of sympathetic action, thymol is parasympathetic, camphor is purely olfactory, and tar has a trigeminal component. The study subject sat freely at a table with an olfactometer. A syringe introduced 2 ml of air into the olfactometer with the odorous substance and the cock was closed.

A cannula attached to the exit channel of the olfactometer was placed into the study subject's nose. At that moment, we asked him to hold his breath and we opened the output cock. The air saturated with the vapor of the olfactory stimulus entered the upper nasal duct. The next time, two additional ml were introduced into the vessel. This procedure was repeated until that time when the study subject sensed the scent at the moment he held his breath. The minimum quantity of air containing the olfactory stimulating substance which causes the scent to be perceived is called the olfaction threshold.

The adaptation time was determined by repeated dosing with threshold amounts every 2 to 3 seconds until that time when the study subject ceased to sense the olfactory stimulating substance while he was holding his breath. The time from the onset of delivering the threshold dose to the moment when the study subject stops sensing the scent is called the adaptation time. It is measured

by a conventional stopwatch; the end of adaptation is considered to be the moment when the study subject gives an assured negative reply. The restoration time was determined after researching the stimulation threshold and the adaptation time. We begin to give an olfactory load of 20 ml every 2 to 3 seconds, over a period of two minutes. Three to five minutes after this, we determined the study subject's perception threshold. We selected as the norm the average thresholds of olfactory sensitivity, of adaptation time and of restoration time (Table 10).

Table 10. Average thresholds of olfactory sensitivity, of adaptation time and of restoration time of perception of people in the control groups (in seconds).

Olfactory Stimulating Substance	Thymol	Camphor	Rosemary	Tar
Threshold of perception	7.1 – 11.9	4.2 – 8.2	4.0 – 10.0	3.7 – 6.9
Adaptation time	68.1 – 108.1	62.0 – 122.0	63.2 – 123.2	72.4 – 152.4
Restoration time	152.1 – 232.1	188.4 – 240.4	180.2 – 302.2	123.4 – 225.2

Aschner-Dagnini Test

In our work we used the method as modified by G.Ya. Liberzon. The study subject is laid on a couch, and after five minutes, his pulse was counted for one minute. Then, using the second and third fingers of the right hand we pressed on both eyeballs simultaneously (lids closed); after 15 seconds we began to count the pulse for 30 seconds and multiplied the result by two. As a standard (normal type of ocular-cardiac reflex) we used a pulse reduction of 4-12 beats per minutes. A highly positive (vagotonic type reflex) was a pulse reduction of more than 12 beats per minute. A negative reflex occurred when the pulse remained unchanged and undistorted. A paradoxical reflex occurred when, in response to the pressure, no slow-down occurred, but an increase in the pulse of more than 2 beats per minute occurred (sympathetic type of reflex).

Clinostatic (Danielopolu) Reflex

When the study subject transitions from a vertical position to a prone position, there occurs a deceleration in the pulse, which depends on reflexive stimulation of the vagus nerve. The research consisted of the following: the pulse of the standing subject was counted for one minute; then he was asked to lie down, and the pulse was counted for thirty seconds, with the obtained result being multiplied by 2. A normal reflex was considered to be a deceleration in the pulse of 4 to 6 beats per minutes as compared with the initial standing pulse.

A positive reflex was a deceleration in pulse of greater than 6 beats per minute. A negative reflex was when the pulse remained unchanged.

Orthostatic (Provel) Reflex

When the study subject transitions from a horizontal position to a vertical, normally the pulse frequency increases, depending on the reflexive stimulation of the sympathetic system.

The research method was as follows. We placed the subject in a horizontal position on a couch, and after 4 to 5 minutes, we counted his pulse. He then transitioned to a vertical position, and at that moment, his pulse frequency was again counted. We considered the norm for this sampling to be an increase in pulse of 8 to 18 beats per minute. A highly positive reaction was an increase in the

pulse of more than 18 beats per minute; and a negative reaction was an increase in the pulse of less than 8 beats per minute.

MacClure-Oldrich Test

The subcutaneous test of MacClure-Oldrich was proposed in 1923 to judge the hydrophilic nature of the skin during various somatic illnesses. When using this method, after appropriate preparation of the skin 0.2 ml of a sterile physiological saline solution was introduced under the skin on the inside surface of the middle third of the left forearm. The norm for resorption was taken to be 35 to 57 minutes.

Ultraviolet Light-Induced Erythema

We determined the response to biodoses of ultraviolet rays in the following manner. The subject was placed on a couch and after five minutes a section of the front surface of the chest was illuminated with a mercury-quartz lamp (with a PRK-4 type burner) situated at a distance of 50 cm. The exposure dose was measured using a Gorbachev dosimeter (from 1 to 6 minutes). The normal time for erythema to appear was 3 hours 50 minutes to 5 hours 20 minutes (control data).

RESULTS

Blood Indices

The circulating blood indices among the research group were analyzed during the first 8 days after the experiments in 1965 and 1974. A repeat analysis was performed after 30-60 days. In all, during this time, 1,221 blood samples were studied.

The analysis of the circulating blood indices for the entire study period did not permit the discovery of any significant differences in their dynamics. All the indices turned out to be within the limits of physiological variations determined by a confidence interval of >95% ($X \pm 2\sigma$) (Table 11).

Table 11. Principal characteristics of blood indices for study subjects before/after irradiation.

Indicator	Sex	Number of subjects	X	m	Variation within limits		
					X±1σ	X±1.5σ	X±2σ
Erythrocytes, 10^{12}/liter	M	1221	4.6	0.35	4.2-4.9	4.0-5.1	3.9-5.3
Hemoglobin, g/l	M	1221	148.1	10.7	137.4-158.8	132.1-164.1	126.7-168.5
Color index*	M	1221	0.93	0.08	0.85-1.01	0.82-1.05	0.81-1.09
Erythrocyte sedimentation rate, mm/h	M	1221	5.5	3.0	2.5-8.5	1.0-10.0	0-11.5
Thrombocytes, 10^9/l	M	1221	247	45	202-292	180-315	157-337
Leukocytes, 10^9/l	M	1221	6.4	1.5	4.9-8.0	4.1-8.7	3.3-9.5
Neutrophils: segmented nuclei, %	M	1221	57.7	8.6	49.1-66.3	44.8-70.6	40.5-74.9
Neutrophils: stab nuclear forms, %	M	1221	3.5	1.8	1.7-5.3	0.3-6.2	0-7.1
Eosinophils, %	M	1221	2.7	1.7	1.1-4.4	0.2-5.2	0-6.1
Basophils, %	M	1221	0.3	0.4	0-0.08	0-1.0	0-1.2
Lymphocytes, %	M	1221	28.9	7.6	21.3-36.5	17.6-40.3	13.8-44.1
Monocytes, %	M	1221	5.9	2.3	3.5-8.2	2.4-9.4	1.2-10.5

***** Color index is the amount of coloring matter in a given unit of blood compared with compared with the amount in a similar unit of normal blood (color index =1). In most secondary anemias the diminution in hemoglobin is relatively greater than the diminution in erythrocyte quality, and the color index drops.[2]

However, we must note that changes in a series of indices (within the limits of normal physiological variations) could to some degree be related to the acute effects of ionizing radiation. Thus, the overall quantity of leukocytes during the first six days suffered changes, resulting in an increase of this index from 5.8E+9/liter to 6.6E+9/liter, with a subsequent reduction to 5.9E+9/liter on days 7 and 8. The change turned out to be significant on days 1 and 6 ($p < 0.05$) (Figure 2).

2 Cabot, Richard Clarke. *Physical Diagnosis*, W. Wood and Company, 1915. pp. 440-441.

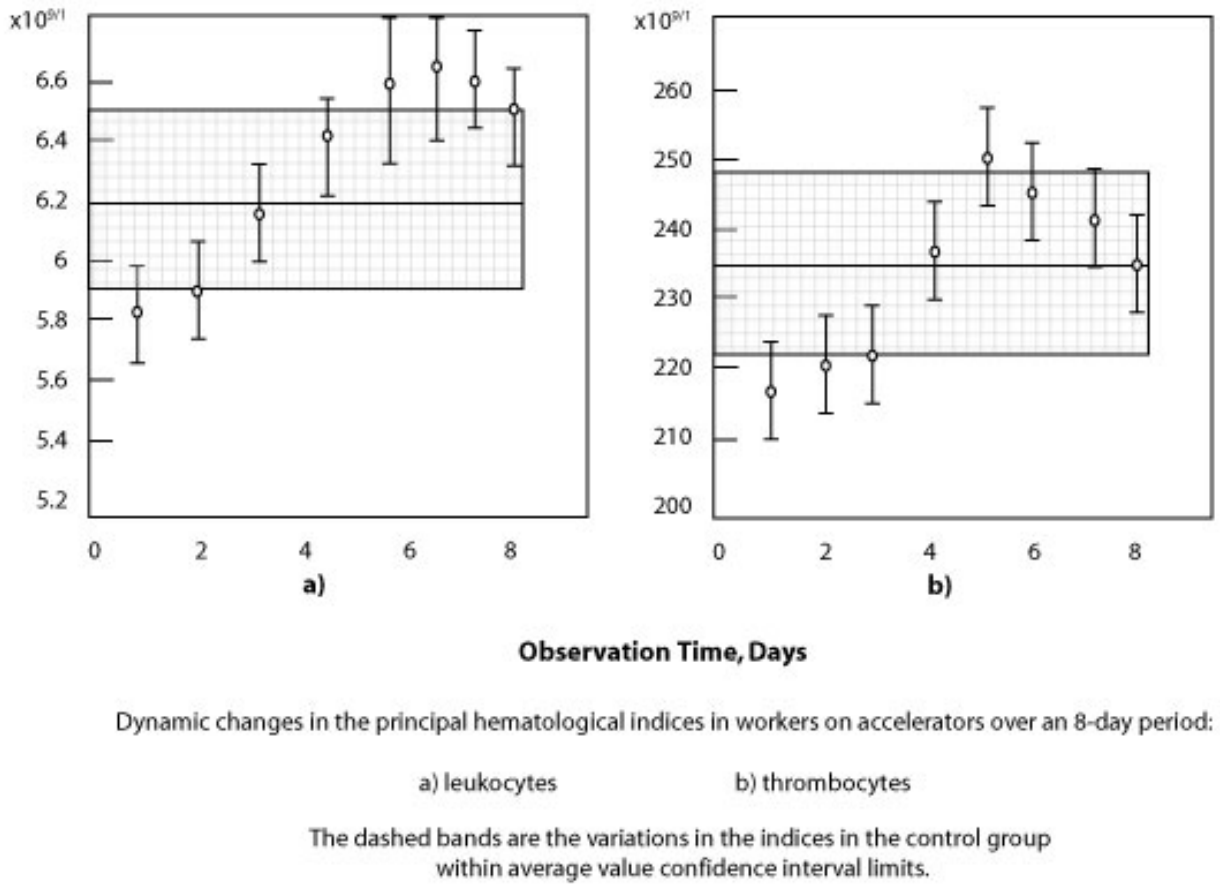

Figure 2. Dynamic changes in the principal hematological indices in workers over an eight-day period.

The same phenomenon was noted when analyzing the dynamics of the index for overall number of thrombocytes. In the first 24 hours after irradiation, the absolute number of thrombocytes among the subjects averaged 215E+9/liter. Then this index slowly rose and by day 5 reached an average of 250E+9/liter ($P < 0.01$); then by day 8, the overall number of thrombocytes reduced again to an average of 235E+9/liter.

No significant changes were discovered in the dynamics of the average indices of erythrocytes and reticulocytes for the first eight days and after 30-60 days. Thus, as a result of our research, no significant changes were recorded in the dynamics of the circulating blood indices among the study groups. Discovered shifts, as a rule, did not exceed the limits of physiological variations from the norm. An insignificant leukocytosis was discovered in the first six days, as well as thrombocytosis in the first five days. After 30-60 days, the principal circulating blood indices of the study groups were within the norms.

Taste and Olfactory Studies

In the initial period (before irradiation), among the study groups, we recorded from 12.5% to 19.4% of the people having hypogeusia, and from 8.5% to 14.5% with hyposmia. We recorded the times for adaptation and restoration of perception of olfactory substances; these were within the

norms. In 82% to 91% of the subjects, we recorded no disturbance in taste and olfactory sensitivity (Tables 12, 13, 14, 15, 16).

Table 12. Average thresholds for taste sensitivity in study subjects.

		1965		1974	
Taste Substances	**Pre-irradiation N = 335**	**1-3 days post exposure N = 310**	**30-60 days post exposure N = 275**	**1-3 days post exposure N = 155**	**30-60 days post exposure N = 146**
	M±m	M±m	M±m	M±m	M±m
Sweet	0.95±0.08*	1.35±0.09*	0.92±0.06*	1.38±0.08*	0.85±0.05*
Salt	0.72±0.05	0.78±0.05*	0.75±0.05	0.76±0.04	0.72±0.05
Sour	0.68±0.06*	0.89±0.07*	0.65±0.05*	0.71±0.05	0.73±0.04
Bitter	0.0015±0.00005*	0.0019±0.00007*	0.0014±0.00005*	0.0016±0.00006	0.0017±0.00007

*Note: * - the differences between the indices for average thresholds of taste sensitivity before irradiation, and 30-60 days after irradiation, are statistically significant as compared with those indices for 1-3 days after irradiation p<0.05)*

Table 13. Number of persons with decreased taste sensation to various taste substances, %.

			1965				1974			
Taste Substances	**Pre-irradiation**		**1-3 days post exposure**		**30-60 days post exposure**		**1-3 days post exposure**		**30-60 days post exposure**	
	Number	%	Number	%	Number	%	Number	%	Number	%
Sweet	56*	16.7	137*	44.2	42*	15.2	61*	39.3	28*	19.1
Salt	42	12.5	56	18.0	39	14.2	31	20.0	29	19.8
Sour	52*	15.5	111*	35.8	40*	14.5	29	18.7	31	21.2
Bitter	65*	19.4	142*	45.8	48*	17.4	64*	41.2	32*	21.9

*Note: * - the differences between data before and after exposure were statistically significant (p<0.05)*

Table 14. Average thresholds of olfactory sensitivity in study subjects.

			1965				1974			
Olfactory Substance	**Pre-irradiation**		**1-3 days post exposure**		**30-60 days post exposure**		**1-3 days post exposure**		**30-60 days post exposure**	
	Number #	M±m	#	M±m	#	M±m	#	M±m	#	M±m
Thymol	335	8.4±0.23*	310	11.2±0.32*	275	8.2±0.21*	155	8.6±0.22	146	8.1±0.2
Rosemary	335	7.2±0.25*	310	10.6±0.3*	275	7.5±0.23*	155	8.1±0.25	146	7.4±0.18
Camphor	335	5.8±0.18*	310	6.2±0.2	275	5.4±0.19	155	7.3±0.24*	146	5.6±0.18*
Tar	335	5.2±0.16*	310	7.3±0.22*	275	5.0±0.15*	155	7.5±0.2*	146	5.5±0.18*

*Note: * - the differences between values obtained pre-irradiation and 30-60 days post exposure vs. values obtained 1-3 days post exposure were statistically significant (p<0.05)*

Table 15. Number of individuals with hyposmia to various olfactory substances, %.

			1965				1974			
Taste Irritators	**Pre-irradiation**		**1-3 days post exposure**		**30-60 days post exposure**		**1-3 days post exposure**		**30-60 days post exposure**	
	Number	%	Number	%	Number	%	Number	%	Number	%
Thymol	49	14.5*	120	38.6*	45	16.2*	27	17.2*	23	15.5
Rosemary	34	10.2*	100	32.4*	27	9.8*	16	10.5	16	11.2
Camphor	42	12.6*	52	16.8	32	11.6	40	25.6*	15	10.8*
Tar	28	8.5*	76	24.6*	27	9.8*	44	28.5*	13	8.8*

*Note: * - the differences between values obtained pre-irradiation and 30-60 days post exposure vs. values obtained 1-3 days post exposure were statistically significant (p<0.05)*

Table 16. Average indices for times of adaptation (AT) and of restoration of perception (RP) for various olfactory substances in study subjects, seconds.

			1965				1974			
Olfactory Substance	**Pre-irradiation N = 335**		**1-3 days post exposure N = 310**		**30-60 days post exposure N = 275**		**1-3 days post exposure N = 155**		**30-60 days post exposure N = 146**	
	AT M±m	RP M±m	AT M±m	RP M±m	AT M±m	RP M±m	AT M±m	RP M±m	AT M±m	RO M±m
Thymol	84.3±2.6	221.4±6.7	88.5±4.2	229±7.3	836±3.1	224±7.5	87.3±3.4	218±6.5	89.2±3.2	220±5.3
Rosemary	92.5±3.9	256.2±8.3	97.4±6.2	261±9.2	95.3±5.8	253±8.6	298.2±5	261±8.3	96.2±4.8	258±8.2
Tar	75.3*±2.9	210±6.3	56.4*±4.5	212±7.1	79.8*±3	218±8.3	76.8±3.2	212±6.5	74±2.1	214±7.1

*Note: * - the differences between the date before and after exposure were statistically significant (p<0.05)*

From 1 to 3 days after irradiation (1965), we recorded dissociated hypogeusia for some taste stimuli among the study individuals.

The average thresholds for perceiving sweet, sour and bitter flavors increased as compared to the initial period ($p < 0.01$). No significant increase occurred in the average perception threshold for saltiness. Among those subjected to irradiation in 1974, on days 1 through 3 we recorded a significant increase in the perception threshold only for sweetness. The taste sensitivity for salty, sour and bitter did not change significantly as compared to the initial period.

An increase in the perception thresholds for some taste substances in the first three days after irradiation led to a significant increase in the number of individuals with hypogeusia. Thus, the number of individuals with hypogeusia for sweet, sour and bitter exceeded more than twofold the initial indices (1965) ($p < 0.01$). The number of individuals with hypogeusia for sweet (1974) also exceeded the indices of the initial level more than twofold ($p < 0.01$).

The same picture was observed in analysis of the results of research on the functioning of the olfactory analyzer.

One to three days after the irradiation, we recorded among the irradiated subjects (1965) a significant increase ($p < 0.01$) in the perception thresholds for such olfactory substances as thymol, rosemary, and tar. Among those irradiated in 1974, we also discovered a significant increase in the thresholds of olfactory sensitivity to camphor and tar one to three days after exposure ($p < 0.01$).

The significant increase in the average thresholds for olfactory sensitivity for some olfactory substances one to three days after irradiation led to an increase in the number of people with

hyposmia. The number of individuals in 1965 with hyposmia to thymol, rosemary and tar increased 2.5 to 3 times ($p < 0.01$). Among those irradiated in 1974, we recorded a two- to threefold increase in the number of individuals with hyposmia to camphor and tar as compared to the initial period ($p < 0.01$).

An analysis of the dynamics of the index for adaptation of perception of a measured amount of olfactory substances showed that there was a reliable reduction after one to three days only among the individuals subjected to irradiation in 1965 ($p < 0.01$). Among those subjected to irradiation in 1974, we found no significant changes in the adaptation time and perception restoration time as compared with the initial period. Thus, the investigation of the functioning of the taste and olfactory analyzer among the irradiated population and test participants permitted us to identify a dissociated reduction in the taste and olfactory sensitivity to several taste and olfactory stimuli one to three days after irradiation. These imbalances were expressed more among those individuals subjected to irradiation in 1965.

In both study groups, a complete restoration of taste and olfactory sensitivity was recorded 30 to 60 days after the onset of irradiation.

Vascular Reactions Dynamics

The use of special tests during the initial period which permit an evaluation of the trends of vascular reactions in males 20 to 40 years of age who comprised our study groups permitted us to record normal reactions in nearly 80% of the cases. The reactions of the vagotonic and sympathetic trends were recorded in a 1:2 ratio.

In the 1-3 days after irradiation in both groups (1965, 1974), when analyzing the results of such tests as Aschner-Dagnini, and the ortho-and clinostatic reflexes, we recorded a nearly threefold increase (as compared to the initial level) in the sympathetic trend reaction. The quantity of parasympathetic reactions in the employed tests did not change significantly (Table 17).

Table 17. Number of study subjects with different trends in Aschner-Dagnini, orthostatic, and clinostatic tests, %.

			1965				**1974**			
Test	**Pre-irradiation N = 335**		**1-3 days post exposure N = 310**		**30-60 days post exposure N = 275**		**1-3 days post exposure N = 155**		**30-60 days post exposure N = 146**	
Aschner-Dagnini:	Number	%	Number	%	Number	%	Number	%	Number	%
Negative	17	5.2	20	6.5	17	6.2	7	4.5	7	5.1
+ Positive	28	8.5*	92	29.8*	29	10.5*	47	30.6*	15	10.6*
Orthostatic:										
Negative	20	6.1	22	7.2	19	6.8	10	6.2	8	5.8
+ Positive	32	9.6*	100	32.3*	29	10.5*	41	26.3*	18	12.3*
Clinostatic:										
Negative	14	4.2	19	6.1	18	6.4	8	5.4	9	6.2
+ Positive	35	10.5*	89	28.6*	27	9.8*	46	29.5*	17	11.8*

*Note: * - statistically significant ($p<0.05$) differences between data before and 30-60 days after exposure vs. 1-3 days after exposure.*

In the 30-60 day period, the number of individuals with imbalances in vascular reactions practically corresponded to the initial period.

When analyzing the results of conducting such tests as the MacClure-Oldrich test for determining the time of ultraviolet erythema, it was established that in 1-3 days, in both groups, the

average time for blister resorption and erythema formation was significantly reduced as compared to the initial period ($p < 0.01$) (Table 18). In this period, in both study groups, we recorded a 4 to 5-fold increase in the number of individuals having vascular reactions with sympathetic trends (Table 19).

Table 18. Average time from exposure to ultraviolet rays until blister resorption (MacClure-Oldrich) and appearance of erythema (minutes).

			1965				1974			
Test	**Pre-irradiation N = 335**		**1-3 days post exposure N = 310**		**30-60 days post exposure N = 275**		**1-3 days post exposure N = 155**		**30-60 days post exposure N = 146**	
	#	M±m	#	M±m	#	M±m	#	M±m	#	M±m
MacClure-Oldrich Test	335	48.3±1.5	310	32.5±0.9*	275	47.2±1.6*	155	33.4±1.8*	146	46.2±1.5*
Appearance of erythema	335	256.5±6.2*	310	216.7±5.1*	275	258.5±7.1*	155	218.3±5.2*	146	259.2±6.3*

*Note: * - statistically significant (p<0.05) differences between data before and 30-60 days after exposure vs. 1-3 days after exposure.*

Table 19. The dynamics of vegetative tests outcomes among groups studied.

Test	**Pre-irradiation N = 335**		**1965**				**1974**			
			1-3 days post exposure N = 310		**30-60 days post exposure N = 275**		**1-3 days post exposure N = 155**		**30-60 days post exposure N = 146**	
	Number	%	Number	%	Number	%	Number	%	Number	%
MacClure-Oldrich Test:										
a) accelerated resorption time	27	8.2*	127	40.8*	3	12.6*	57	36.8*	17	11.8*
b) delayed resorption time	36	10.6	48	15.5	36	13.0	23	14.8	18	12.3
Appearance of erythema from ultraviolet radiation:										
a) accelerated reaction time	22	6.5*	112	36.2*	20	7.2*	46	29.5*	10	7.1*
b) delayed reaction time	40	11.8	42	13.4	37	13.5	19	12.5	21	14.3

*Note: * - statistically significant (p<0.05) differences between data before and 30-60 days after exposure vs. 1-3 days after exposure.*

In the 30-60 day period, the distribution of individuals with various vascular reactions corresponded to the initial period; during the entire extent of the investigation, the number of individuals with vagotonic trending vascular reactions did not change significantly.

Analysis of the combination of the established pathological changes in the system of analyzers and in the differently trending vascular reactions among the study groups during the periods before and after irradiation permitted us to ascertain the presence of a nearly twofold increase in the number of individuals with these imbalances 1 to 3 days after irradiation (Table 20). The majority of the discovered imbalances in this period completely leveled off after 30-60 days from the onset of irradiation.

Thus, the conducted research permitted us to record among young males subjected to the combined effects of external irradiation and internal contamination by radioactive fission products from the venting cloud of an underground nuclear explosion reactions of the central nervous system and of blood vessels which were expressed by dissociated disorders in taste and olfactory sensitivity, as well as by sympathetically trending vascular reactions.

Radiation Situation After Test

The low-lying radioactive cloud, which formed as a result of the venting of radioactive fission products at the adit portal, nine minutes later had reached the stand-off area for experiment participants (162 individuals) located at a distance of 9-10 km from the explosion epicenter. At that time, 127 people were along the axis of the track, and 35 were 2.5 km off to one side from the axis of the radioactive track. The time to form the track took about 12-13 minutes. The radioactive fission products of the explosion cloud were significantly enriched with isotopes possessing gaseous precursors (strontium-89, yttrium-91, cesium-137, barium-140), and also highly volatile isotopes (iodine-131, 135). In addition, other isotopes were present in significant quantities: molybdenum-99; silver-111; ruthenium-103, 106; tellurium-133).

The maximum radiation levels along the axis of the track reached 250 R/hr. The calculated exposure dose on the open territory within the stand-off limits of the 127 people during the passage of the explosion cloud was 265 mGy. The time that people remained within the track was 10-20 minutes. The doses of external gamma irradiation for them, according to individual dosimeters DS-50 was 220 $\pm$ 30 mGy. Up to 20 mCi (740 MBq) of 10-20 minutes old radioactive material was able to enter the human body.

The doses for external beta irradiation on uncovered sections of the skin could reach roughly 2.00 Gy. The irradiation doses for the 35 individuals located off to the side of the axis did not exceed 10-20 mGy.

Depending on the irradiation dose and the conditions for examination, the test participants were divided into three groups for analysis. The first group included 11 people who, at the time the radioactive cloud passed, were located along its axis; they were examined at a permanent medical facility. The second group included 11 people who were located in the same place, but were examined in ambulatory conditions. The third group included 35 people who, at the time the cloud passed, were located at the same distance from the explosion epicenter, but were 2.5 km off to the side of the axis of the radioactive track.

Considering the lack of initial health data in the majority of the examined people, we separated out a fourth group, a control group containing 49 people.

A therapist, radiologist, neuropathologist, ophthalmologist, otorhinolaryngologist and a hematologist all participated in the clinical examination of the test participants. The people in Groups II and IV (control) were examined in ambulatory conditions 10 days after the explosion. People in Groups I and II were observed during the 7 months after the effects. The people in group I were examined in the permanent facility during the first 5-6 weeks.

The hematological research included a general clinical investigation of the blood defining the content of thrombocytes and reticulocytes, a luminescent-microscopic investigation of the formed elements of the circulating blood, and a marrow puncture investigation. In addition to this, we determined the basic exchange, took electrocardiograms, looked through capillary scopes, and made radiometric emissions analyses.

The results of the clinical-experimental investigations were confirmed by statistical processing including mean (X), average quadratic deviation (δ), average error (m), and by using regressive analysis.

To compare the results of the investigations, conducted on the experimenters and the populace during the time the radiation factors from the underground nuclear explosions affected the subjects, an experiment was also conducted on animals. The purpose of this investigation was to study the clinical-morphological features of combined radiation injuries in 25 dogs and 108 rats after staying on the ground at the moment of passage of the low-lying radioactive cloud from the nuclear explosion accompanied with an ejection of soil.

The animals, which were placed from 0.4 to 1 km from the explosion center, were covered by the radioactive cloud within the first 3.5-7 minutes. In the subsequent 4 hours (before removing the animals), additional irradiation and contamination was possible due to the gas plumes which exited out of the explosion cavity.

To prevent the ingestion of radioactive matter through the digestive organs, the dogs were fitted with muzzles. The rats were in metal mesh cages (up to 20 per cage). Internal contamination of the rats could occur by inhalation, and also orally due to their licking radioactive matter from their hair and from the walls of the cages. One of the cages at the 1 km mark was covered with a polyethylene film and had a reduced oxygen supply, which prevented the possibility of internal contamination of the animals.

The doses of external gamma irradiation recorded by the IFK film dosimeters, which were attached to the dogs' collars and to each rat cage, registered 120-180 R at a distance of 0.4 km, and 38-90 R at a distance of 1 km.

It turned out to be more difficult to determine the quantity of radioactive material entering into the body through the respiratory organs, since a significant number of these radionuclides have a short half-life and many isotopes were gaseous in form. The quantity of radioactive material which entered into the body was determined by calculation, starting with the concentration in the air, the volume of lung ventilation and the duration of being held inside the lungs. Roughly, at a distance of 0.4 km, close to 20 mCi (740 MBq) of radioactive fission products could have entered the dogs' bodies, and at a distance of 1 km, close to 10 mCi (370 MBq).

Table 20. Dynamics of alteration of sensations of taste and smell over time.

Number of Individuals with Pathology	**1965**			**1974**	
	Pre-irradiation	**1-3 days after irradiation**	**30-60 days after irradiation**	**1-3 days after irradiation**	**30-60 days after irradiation**
All subjects studied	335	310	275	155	145
Number of people w/pathology	62	120	56	57	29
%	18.4	38.8	20.4	36.8	19.6

Clinical-Hematological Changes in Test Personnel Affected by Radiation

Group I. Until the moment the effects occurred, all individuals in this group were, for all practical purposes, healthy.

Soon after irradiation, eight of the eleven study subjects felt generally worse: headache, dizziness, overall weakness, nausea, tickling in the throat, and somewhat later, vomiting and loose stools. Headache in two people appeared 30 minutes after the test and in three people by the end of the first day, with the remainder feeling a headache on the second and third day. The pain had a compressive character, and was localized in the forehead-temporal area and continued for three to five days after the test.

Symptoms of digestive-intestinal disorders such as nausea, vomiting, loose stool and anorexia were noted in five of the eleven study subjects. Nausea appeared most quickly, which affected three of the individuals within 30-40 minutes. Only one individual did not develop nausea until the second day after irradiation. Three individuals vomited only once, and another three vomited three times during the first three days. Loose stool with no pathological admixtures was observed in three of the 11 study subjects. Loose stool occurred in one individual six hours after irradiation, and in the others, two days later. The frequency of stools was one to three times in a one to two day period.

Somewhat rarer in the individuals of this particular group were changes in the skin, mucus membranes of the upper respiratory airways, and the eyes. Edema and a burning feeling in the face occurred in one individual on the second day after irradiation. Rhinitis and conjunctivitis occurred in two of the 11 study subjects: in one of them they occurred after roughly six to eight hours, and in the other on the second day after irradiation.

The duration of the symptoms of this initial reaction in the study subjects was three to five days. By the sixth day, all the above-noted signs of deterioration in the study subjects' general health had passed. In addition, data from the instrumented researches indicated the presence of weakly expressed changes in the cardiovascular system. Thus, in electrocardiogram investigations, on the fifth day after irradiation, we recorded in eight of the 11 study subjects a reduction in T wave voltage in all leads. During the same time frame, using capillaroscopy, we discovered in six individuals various changes in the form of background cloudiness, retort-like dilation of the venous capillaries, as well as sections of hemorrhage.

The results of the neurological investigations on day five after irradiation indicated the presence of mild vegetative disorders in five of the 11 study subjects. The most frequent symptoms in these time periods were as follows: mild eyelid tremor, cyanosis and hyperhydrosis of the wrists, and, less frequently, emotional lability, and instability in the Romberg position.

Over a period of two to five weeks after the underground test, the overall health of the study subjects was satisfactory. Only a few of them complained periodically of general weakness and poor sleep. After eight to nine days two of the individuals had single petechiae on the chest and spine, which continued for a period of three days (during the time period of maximum reduction in the number of thrombocytes in the circulating blood).

In ophthalmologic studies on day 18 after the irradiation we discovered spotty hemorrhages of the palpebral conjunctiva and bulb-like dilation in the venous capillaries in nine of the 11 study subjects, and in one individual hemorrhages in the episclera of the left eyeball. The discovered changes were almost completely gone by the end of the fourth day after appearance of these effects.

In the dynamics of the basal metabolism of the study subjects, we saw a tendency toward a reduction in the period of two to three weeks after the irradiation (from -2% to -17%).

The data for hematological investigations revealed moderately expressed changes in the content of the white cell series, reticulocytes and thrombocytes in the circulating blood, as well as myelokaryocytes in bone marrow.

The dynamics of the changes in the content of leukocytes were characterized by an increase in their levels in the first three days and by two subsequent waves of reductions during days four to 18 and days 25 to 54 after exposure. Within 24 hours after irradiation, the group's average number of leukocytes was 9,449 $\pm$ 1,220 per microliter. In individual cases, the number of these cells during this time period reached 12,400 to 12,800 per microliter. The increase in the leukocyte level occurred mainly due to an increase in neutrophils and was accompanied by a shift toward immature nuclei.

The minimum content of leukocytes was noted on day 10 after irradiation, when their quantity for the group was reduced to an average of 4,777 ± 410 cells in one microliter, or by 31.5% as compared to the control ($p < 0.001$). The reduction in the number of cells from day two to day ten can be expressed by the following exponential relation:

$$P_t = 136\ e^{-0.075t}$$

where P_t is the number of leukocytes as a percentage of the control at time t in days.

Using the data of this equation, the period to reduce the number of leukocytes by half was 9.2 days. However, in individual cases, the number of leukocytes during this time period decreased to 3,200, and in subsequent days, decreased down to 2,700 per microliter. The second wave of reduction in the leukocyte level had a less pronounced character. The reduction in number of these cells, on average for the group, was 21.3 to 23.3%.

Restoration in the number of leukocytes occurred after the first reduction wave at a rate of 2.3 $\pm$ 0.5% per day. After the second reduction wave, the restoration rate was significantly lower. Not until seven months after the test did the number of these cells reach the control values for the study subjects.

Changes in the number of neutrophils occurred in parallel with the quantitative changes in the leukocytes. The average absolute number of neutrophils on day 2 was 6,710 $\pm$ 1,270 cells per microliter, or 70.7% higher than in the control ($P = 0.05$). By day 10, the number had decreased to 2800 $\pm$ 278 cells per microliter, or by 28.8% ($P < 0.001$). The reduction in the level of neutrophils from day 2 to day 10 was characterized by the following relation:

$$P_t = 170\ e^{-0.097t}$$

where P_t is the number of neutrophils as a percentage of the control at time t in days.

The period of time to halve the number of neutrophils here was close to 7 days. During the second reduction wave, the absolute number of neutrophils, on average for the group, decreased by a lesser degree, by 7.6 to 12.8%. The restoration in the number of these cells from day 10 to day 18 occurred at a rate of 3.3 $\pm$ 1.4% per day. Seven months after the test effects, the neutrophil content was fully restored.

The average absolute number of lymphocytes reached its maximum reduction on day 7 after the test, when the group average was 1,610 $\pm$ 110 cells per microliter, or 35% less than in the control ($p < 0.01$). The reduction in the number of cells during this time period was characterized by the following exponential relation:

$$P_t = 94.2\ e^{-0.056t}$$

where P_t is the number of lymphocytes as a percentage of the control for time t in days.

During the second reduction wave, the number of these cells was 36.6% less than in the control ($p < 0.001$). A total restoration in the lymphocyte content did not occur, even by the seventh month after the test. According to the data from the ambulatory observations, the average absolute number of lymphocytes during this period was 1,981 $\pm$ 222 cells per microliter, or 22% lower than in the control ($p = 0.05$).

The number of eosinophils decreased over the extent of the entire observation period. Their minimum content was noted on day 10 after the test, when the average absolute number was 40 $\pm$ 10 cells per microliter, or 74.6% lower than in the control ($p < 0.05$). During the second reduction wave, the number of these cells was reduced by 37.1 to 43.6% ($p < 0.05$).

The dynamics in the changes in monocyte content were characterized by a moderately expressed monocytosis in the first days, and a reduction in their number during the following time periods: from day 5 to day 7, from 9 to 18, and from day 28 to day 38 after the test. The greatest expressed monocytopenia was observed on days 10 and 38, when the number was respectively 134.3 $\pm$ 17.6 and 130.9 $\pm$ 19.8 cells per microliter, or 55.8 and 56.8% lower than in the control ($p = 0.05$).

Structural changes in the leukocyte series were not discovered during the usual hematological staining of blood smears. However, using luminescent-microscopic investigations, we observed a wave-like increase in the number of cells having a pathological luminescence. The maximum increase in the content of the damaged cells in the circulating blood took place in the first three weeks after the irradiation, when their number increased to 17-26%, versus 5-10% in the control. By day 38, the number of pathologically luminescent cells decreased to 9-13%. The changes in cell luminescence occurred to approximately the same extent in both neutrophils and lymphocytes. Mainly, the change in the character of luminescence of the nuclei occurred mostly in those nuclei whose color varied from yellow to red. A portion of the cells looked like red balls, and consequently, the structures of the nuclei and the cytoplasm were indistinguishable.

The duration and the level of the quantitative shifts in thrombocytes were roughly the same as those noted above relative to leukocytes. Thus, two days after radiation from the test, the average number of thrombocytes increased 26.2%. Then their content began to decrease rather rapidly, and by day 10, it was 135,780 $\pm$ 10,000 per microliter, or 32.7% lower than in the control ($p < 0.001$). The reduction in the number of thrombocytes from day 2 to day 10 after the effects is described in the following exponential relation:

$$P_t = 127\ e^{-0.046t}$$

where P_t is the average absolute number of thrombocytes as a percentage of the control for time t in days.

In individual cases, the number of thrombocytes during this time period decreased to 105,000 per microliter. If we then consider that during the first days after irradiation the number of thrombocytes in a given study subject was 262,000, and after restoration, 200,000 per microliter, then it becomes clear that in some people in group 1, the content of thrombocytes after radiation decreased almost twofold.

Restoration in the thrombocyte content occurred by the end of the first month after irradiation.

We did not find any significant changes in the red blood indices. The hemoglobin content in the study subjects varied from 13.4 to 14.8 g/dL, and erythrocytes, 4.3 to 5.2 million per microliter. The color index was 0.85 $\pm$ 0.01 to 0.90 $\pm$ 0.01.

The relative average number of reticulocytes changed in a wave-like manner, varying between 4.4 $\pm$ 0.3 to 15.1$\pm$ 2%, versus 4.7 $\pm$ 0.3% for the control. The maximum increase in the reticulocyte number was observed on day 18 after the test, when the relative number in individual cases reached 30%. Changes in the reticulocyte count were characterized by a shift to the right in the first few days, and an almost complete normalization by the end of the first month after irradiation.

Bone marrow was studied in eight individuals on day 24 after the test. The number of nucleated cells varied from 34,000 to 82,000 per microliter; the group average was 60,877 $\pm$ 6,130, versus 100,000 per microliter according to Kh.Kh. Vlados and E.F. Finestein (1953). Thus the ratio of individual progenitor cells of bone marrow was normal. The proportion of neutrophil, erythroid and lymphoid progenitor cells was, respectively, 62.1 $\pm$ 2.5, 24.0 $\pm$ 0.22 and 8.7 $\pm$ 1.3%, with other bone marrow elements constituting 5.1%. In individual cases, a moderately expressed reduction (up to 15%) in the erythroid series cells took place.

On the basis of a distinctly expressed primary general reaction, the degree of hemopoietic depression, and also a subsequent weakly expressed occurrence of hemorrhagic syndrome in individual study subjects (as evidenced by single petechiae on the skin of the torso, conjunctival hemorrhages, and reduction in thrombocyte content), and the changes in the functioning of the central nervous system, five of the 11 study subjects were diagnosed as having acute radiation illness of light degree of severity (first degree). The remaining six individuals were considered to have had a radiation reaction.

Treatment was given with preparations of bromine and a broad vitamin complex. During the first few days, the study subjects took barium sulphate as an adsorbent.

Features of the clinical course of illness in the first ten days in these particular cases included significant polymorphism of symptoms, longer duration of the primary general reaction, a relatively rapid decrease in the number of elements of the peripheral blood, and a primary reduction of the numbers of eosinophils, monocytes, neutrophils, and thrombocytes. There was a lesser decrease in the number of circulating blood cells during the second reduction and an extended period of restoration of hemopoiesis.

Group II. This group included 116 test participants who were examined in ambulatory settings. They were all located on the axis of the radioactive track when it was formed. The irradiation doses were the same as for those in Group 1.

Prior to exposure, the general health of the group was satisfactory. Data from 28 of the group were obtained from a dispensary examination prior to the irradiation. The arterial blood pressure was: systolic 121.5 $\pm$ 2.5, and diastolic 74.6 $\pm$ 1.2 mm Hg. In the circulating blood hemoglobin content was 13.2 $\pm$ 0.15g%, erythrocytes 4,770,000 $\pm$ 70,000 per microliter, leukocytes 6,980$\pm$ 220, and ESR 4.8 $\pm$ 0.4 mm per hour.

Soon after irradiation, the majority of the group (similar to Group 1) complained about feeling generally worse, with complaints of headache, dizziness, overall weakness, nausea, dryness of the mouth, eye irritation, etc. (Table 21).

Table 21. Character and frequency of symptoms of the initial general reactions in Group II individuals.

Symptoms	**Number of people with complaints**			
	Group II		**Control group**	
	No.	**% of total affected**	**No.**	**% of total affected**
Headache	51	43.9	4	8.2
Dizziness	21	18.1	--	--
Generalized weakness	26	22.4	1	2
Poor sleep	15	12.9	--	--
Somnolence	6	5.3	--	--
Anorexia	9	7.8	--	--
Nausea	35	30	--	--
Vomiting	14	12.1	--	--
Loose stool	7	6	--	--
Stomach pains	5	4.3	--	--
Tickling in throat	11	9.7	--	--
Edema of the eyelids and face	7	6	--	--
Eye irritation	11	9.7	--	--
Pains in the thyroid area	3	2.6	--	--
Increased perspiration	3	2.6	--	--
Other complaints	50	43	6	12.2
Total with complaints of feeling worse	92	79.4	11	23.4

From this table, it follows that the symptoms of the initial general reaction occurred in roughly 80% of the overall number of study subjects. We also noted significant polymorphism in the expressed symptomatology. In the first instance, symptoms arose which indicated disturbances in the functioning of the central nervous system and the digestive organs. Somewhat less frequently, we saw conjunctivitis and rhinitis. The duration of the individual symptoms, as well as the duration of the initial reactions in Group II individuals, did not differ from the above-noted times of development and the course of the first phase of illness formation in the Group I individuals. On day 6, the overall state of the study subjects improved significantly. However, they continued to have individual

neurological symptoms and changes in the organs of vision. On neurological examination, symptoms of mild vegetative-vascular disorders were noted after two and four weeks in 35 and 24% of the cases, respectively. After seven months, the demonstrated changes resolved completely. The data from ophthalmologic examinations 10 to 11 days after exposure indicated the presence of hyperemia of the conjunctiva in 26% of the cases and single-point hemorrhaging in the conjunctiva in 15% of the cases. One month after irradiation, the expressed changes had resolved.

The character of the hematological changes in the Group II individuals practically did not differ from the course of changes in hemopoiesis in the test participants examined in the hospital. In addition, the level of reduction in content of the formed elements in the circulating blood of those examined in ambulatory facilities turned out to be less. Thus, the overall number of leukocytes and the absolute number of lymphocytes, monocytes, and eosinophils experienced maximum reductions of only 17, 31, 38 and 50%, respectively, in Group II individuals.

We did not note any significant changes in the content of hemoglobin, erythrocytes and thrombocytes in Group II individuals.

Despite the less pronounced level of reduction in content of formed elements of the blood, they were restored slowly. Seven months after irradiation, the absolute number of lymphocytes and eosinophils continued to remain lower by 20% ($p = 0.05$) and 50% ($p < 0.01$), respectively, than in the control group.

On the basis of these clinical-hematological changes in the individuals of this group, we considered 2/3 of the cases to have had a radiation reaction; the rest were considered healthy, for all practical purposes.

The capability of individuals in Groups I and II to perform work did not suffer.

Group III. In our examinations in ambulatory settings ten days after exposure, the picture of the circulating blood did not differ from the blood indices of the control group. The anamnesis data [patient histories—Ed.] indicated a lack of symptoms of disturbances in general health even in the first days after exposure. All of them were considered to be healthy for all practical purposes on the basis of the examination results.

Clinical-Morphological Changes in Animals Subjected to Radiation

In three of 13 dogs who were at the 0.4 km marker (and received external irradiation doses of 1.42, 1.50 and 1.80 Gy), a severe level (Degree III) of acute radiation injury developed, with fatal outcomes between the 21st and 28th days. Five of the animals were diagnosed with medium radiation illness (Degree II), and the other 5 with mild radiation illness (Degree I).[2]

The changes in blood indices were typical for acute radiation sickness. At the height of the illness for the severe level of injury, the number of leukocytes in the circulating blood decreased down to 0.4E+9/liter to 0.7E+9/liter, with an average of 2-3E+9/liter. During the course of mild radiation injury leukocytes decreased down to 3-4E+9/liter, as compared to 10-12E+9/liter prior to the test.

In eight of the dogs at the 1 km marker, a mild radiation injury developed, with a clear leukopenic reaction toward the end of the 1st week (to 4.7E+9/liter $\pm$ 0.5E+9/liter). A second wave of leukopenia occurred toward the end of the 3rd week, when the leukocyte content was at 5.4E+9/liter $\pm$ 0.7E+9/liter. In individual animals, the number of leukocytes decreased to 3.1-3.2E+9/liter.

When the three deceased dogs were dissected, they were diagnosed with acute radiation sickness with manifestations of hemorrhagic syndrome. Hemorrhage was apparent in the subcutaneous cellular tissue, under the epicardium, in all lobes of the lungs, in the mesentery, the serous and mucous membranes of the small and large intestines, and in other internal organs. In all three dogs, the radiation illness was complicated by necrosis of the palatine tonsils. Two of them also had focal hemorrhagic pneumonia.

During microscopic examination of the organs and tissues of four dogs (one was from the 0.4 km marker) that were sacrificed within the first few days, we discovered focal destructive changes in the thyroid tissues.

In dogs that died within three to four weeks, we observed the following:

- in the thyroid: expression of necrobiotic changes extending to necrosis and desquamation of the follicular epithelium;
- in the lungs: multiple foci of hemorrhage and necrosis, together with spots of fibrinous hemorrhagic pneumonia without cellular inflammatory reaction;
- in the kidney: focal hemorrhages;
- in the liver: necrobiosis of liver cells, edema, atrophy of the [centrilobular] hepatic cords, derangement of lobular architecture; and
- in the spleen, bone marrow and lymph nodes; destruction of cellular elements and manifest edema.

In test rats, Degree I (mild) to Degree III (severe) radiation injuries occurred, often with fatal results.

During a three-month observation period, there was no mortality in the control group or in the rat group subjected to only external irradiation at a dose of 0.71 to 0.72 Gy. Among the animals with combined effects (external dose of irradiation was 0.71 to 0.72 Gy), mortality during this period was 31 to 65%.

The hemopoietic system reactions in test rats corresponded to changes characteristic for acute radiation illness. In those subjected to only external irradiation at a dose of 0.71 Gy, we noted a

relatively shallow leukopenia in the first 2 to 8 days with a 25 to 37% reduction in the number of leukocytes and a subsequent normalization of the blood picture by day 11. Rats whose respiratory organs were not protected at the same doses of external irradiation (0.71 to 0.72 Gy) experienced leukopenia, which was much more clearly expressed during the first week. For the entire group the average number of leukocytes in the circulating blood, as compared to the initial data, decreased 39 to 67%, and in individual cases 74 to 77%. When dissecting the deceased rats, as a rule, we noted manifest pooling of blood, individual and multiple foci of hemorrhaging in the lungs, and in individual cases, foci of hemorrhagic pneumonia, alternating with emphysema and atelectasis.

During histological investigations of the thyroid glands, we noted pronounced necrobiotic changes in the follicular epithelium with desquamation, as well as destruction of the individual follicles, especially in the central zones of the gland. When examining the lung samples under a microscope, the majority of the deceased rats had hemorrhage, and in the openings of the small and medium bronchi there was a fibrinous hemorrhagic exudate with an admixture of desquamated epithelial cells. In 30% of the cases, we discovered foci of fibrinous hemorrhagic or necrotic pneumonia without a leukocytic reaction. In the hemopoietic organs (bone marrow, spleen, lymph nodes) we noted signs of expressed foci and aplasia of hemopoietic tissue, and in the liver we saw necrobiotic changes, hemostasis, edema, and atrophy of the centrolobular hepatic cords. In the kidneys we often encountered hemorrhagic foci within the parenchyma of the marrow and cortical layers.

After three months, the test and the control animals were studied for iodine uptake functioning of the thyroid gland by introducing indicated quantities of I-131 into them and taking measurements, while they were alive, of the doses of gamma radiation in the area of the gland. The results of this research indicated that in rats subjected only to external irradiation at a dose of 0.71 Gy, the functioning of the thyroid gland had practically no difference from the control (Table 22).

Table 22. Changes in the activity of thyroid gland of rats over time as percentage of the recorded dose.

Group	**Distance (km) from explosion epicenter**	**Dose of external irradiation (Gray)**	**Time Period During Research**					
			2 hrs	**7 hrs**	**9 hrs**	**1st day**	**2nd day**	**3rd day**
1	0.4	1.20	11.1	17.4	20.0	19.8	16.4	14.4
2	0.4	1.25	16.9	27.8	34.6	29.2	24.3	20.0
3	1.0	0.72	20.4	31.3	38.3	33.5	26.1	20.0
4	1.0	0.71	7.1	13.3	17.0	15.9	14.2	11.4
5	1.0	0.71*	19.5	25.4	30.2	24.6	22.5	19.4
Control	--	--	11.8	25.0	30.1	24.6	19.8	17.1

**- Animals in group 5 were protected against internal irradiation.*

Unfortunately, it was not possible to calculate the whole body internal irradiation dose values from the incorporated short-lived fission products from the underground nuclear explosion with the data from our radiometric research. We also were unable to experimentally determine the dose from external beta irradiation. However, from our analysis of the material it follows that the biological

effects, as estimated according to the levels of leukopenia, mortality and morphological changes in the organs and the tissues of the deceased animals, were not appropriate for the low dose of external irradiation received. To a large extent these effects could have been caused by the internal irradiation due to the incorporated isotopes and to some extent by the external beta irradiation of the skin. However, we discovered no visible signs of injury to the skin or mucous membranes in either the rats or the dogs.

The dogs at the 0.4 km marker, where the registered irradiation doses were 1.20-1.80 Gy (average of 1.50 Gy), developed moderate and severe radiation injuries, with fatal outcomes in 23% of the cases. This fatality rate is roughly equivalent to the effect of unilateral general gamma irradiation at a dose of 4.00 Gy. If we consider that the effect of irradiation from all sides delivered by the radioactive cloud could be roughly 1.5 times higher than that from unilateral irradiation, then in this case the effect of internal irradiation turned out to be equivalent to a dose of 1.75 Gy. In other words, the contribution of the external and internal radiation components to the overall injury could be considered roughly equal.

At the 1 km marker, the effect of the radiation reaction in dogs could be roughly estimated at an equivalent dose of 2.00-2.50 Gy of unilateral gamma irradiation, though the exposure doses actually registered were 0.40-0.90 Gy.

In rats protected from internal contamination, the changes in the circulating blood indices corresponded roughly to the dose of 0.72 Gy of external irradiation actually received. In rats with unprotected respiratory and digestive organs that were irradiated at the same dose, the effect, as estimated by leukopenia level, mortality and morphological changes, was roughly equivalent to unilateral irradiation by a dose of 5.00 to 6.00 Gy.

Thus, the equivalent dose value in rats exceeded the actual recorded exposure dose value of external gamma irradiation by roughly 7 to 8 times. Clearly, this can be explained by the additional internal irradiation due to radioactive material entering through the respiratory and digestive tracts, as well as the higher effectiveness of external and internal beta irradiation as related to the relatively low geometric dimensions of the rats' organs.

Hence, the results of our experiment indicate that in conditions of a low-lying radioactive venting cloud resulting from an underground nuclear explosion with the ejection of soil, internal irradiation determines to a significant extent the level of intensity of the radiation injuries.

Changes in peripheral blood of dogs from combined effects of external and internal contamination due to radioactive fission products from the venting cloud from an underground nuclear explosion.

We made clinical observations and systematically studied the blood of the test and control animals (erythrocytes, hemoglobin, leukocytes, neutrophils and thrombocytes). In addition, we performed some biochemical and immunological research.

Three of the 13 dogs from marker 0.4 km developed severe acute radiation injury, with death occurring at days 21 to 28. The remaining 10 dogs suffered mild or moderate radiation illness.

All the dogs at the 1 km marker were diagnosed with mild radiation illness.

In the dogs that died with severe radiation illness we noted clinically a reduction in mobility and a moderate reduction in appetite during the beginning of the illness. As the illness climaxed, loose black colored stool appeared, and the body temperature increased up to 40.3 to 40.7 degrees. [Normal range in dogs is 37-40 degrees C.] We noted as well necrotic ulcerous changes in the

mucous membranes of the mouth. The dynamics of the blood indices in these dogs were typical for severe acute radiation injury and were characterized by a significant depression of hemopoiesis right up to the analysis of the hemopoietic organs (Figure 3). It should be noted that the initial changes in the circulating blood in these animals were identical. Thus, we observed in two dogs, on the second day after the exposure, a sharp drop in the overall number of leukocytes from 10.2-12.3E+9/liter down to 3.5-4.6E+9/liter. This was mainly due to a reduction in the number of lymphocytes about twenty-fold, from the initial levels of 175-184E+9/liter.

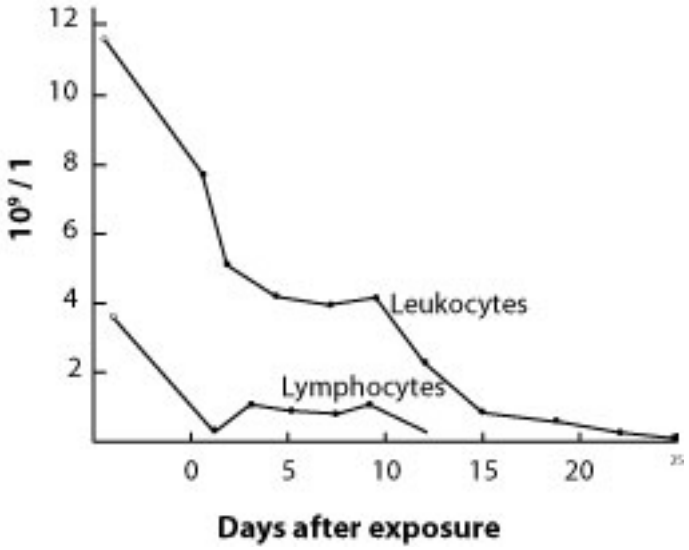

Figure 3. Dynamics of numbers of leukocytes and lymphocytes in dogs with radiation illness.

Another picture was observed in a third of the dogs with the same level of radiation injury. On the second day, we noted in this group a neutrophil leukocytosis with an increase in immature forms. The absolute number of neutrophils increased from 5.35E+9/liter to 14.0E+9/liter, or 2.6 times. The neutrophil leukocytosis was accompanied by a one-time significant increase in the number of thrombocytes from 369.6E+9/liter to 806E+9/liter, or 2.2 times. The absolute number of lymphocytes on the second day decreased down to 540 cells per cubic millimeter, or 4.8 times.

From the third day, the quantitative changes in the circulating blood indices in all three dogs were roughly identical and were characterized by a progressive suppression of hemopoiesis. So, the average number of leukocytes by the end of the first week decreased down to 3.9E+9/liter, or 2.8 times, and by the end of the second week to 2.25E+9/liter, or 4.8 times as compared to the initial data. In the beginning of the second week we noted a still more precipitous drop in the leukocyte level, to 400 to 670 cells per cubic millimeter, and before death (on the 18th to the 24th days) to 200 cells. The profound leukopenia was accompanied by a significantly expressed reduction in the number of eosinophils and monocytes (Figure 4).

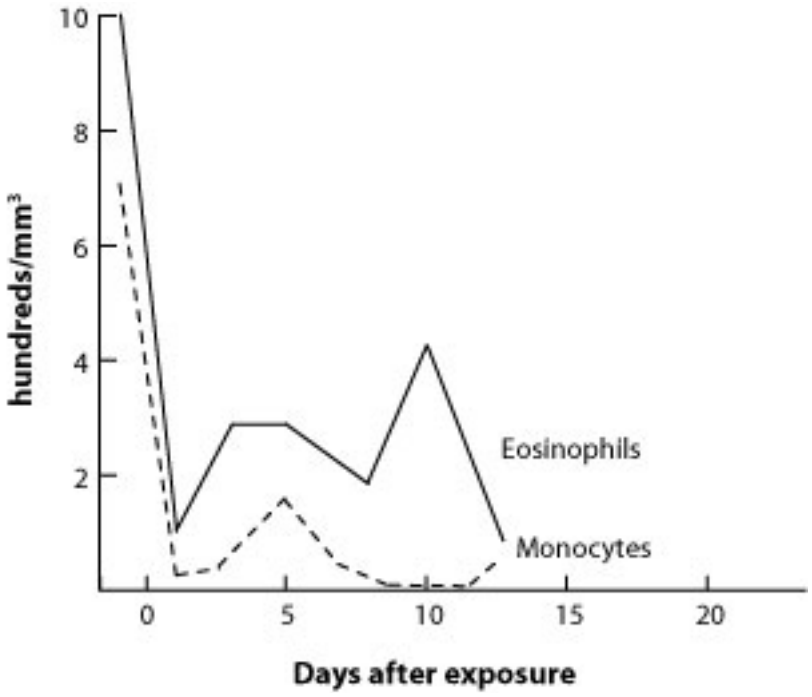

Figure 4. Dynamics of eosinophils and monocytes in dogs with radiation illness.

The dynamics of the thrombocytes were characterized by a gradual reduction in levels before the 7th day and a more expressed thrombocytopenia by the 9th day, when the average number of thrombocytes was 76E+9/liter. By the 12th day, the number of thrombocytes fell even more to 22.8E+9/liter, nearly 16 times as compared to the initial background values (Figure 5).

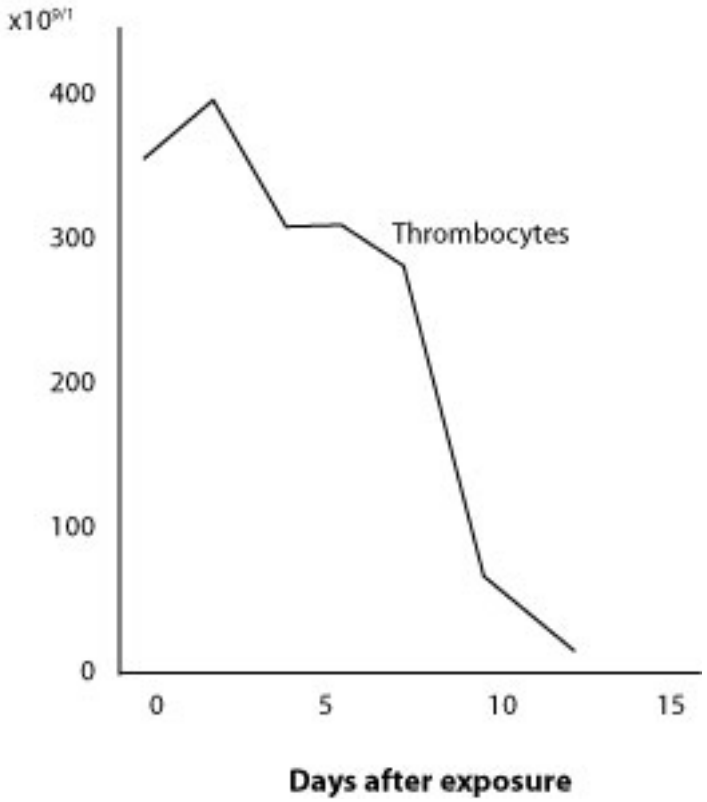

Figure 5. Dynamics of thrombocytes in dogs with radiation illness.

The changes in the red blood indices resulted in a moderate reduction in the number of erythrocytes and hemoglobin around the 2nd and 3rd weeks. However, before death, we observed a sharp drop in the number of erythrocytes to 1.8E+12/liter. The sedimentation rate during the climax of the radiation illness increased to 72 - 81 mm/hr.

Thus, in conditions where the animals were kept in the track of the radioactive venting cloud from an underground nuclear explosion with the ejection of soil, during external irradiation doses on the order of 1.20 to 1.80 Gy and internal contamination via freshly produced radioactive fission products, a severe radiation illness developed, with profound and devastating injury to the hemopoietic organs. Similar states, as we know, can be observed at doses of external irradiation on the order of 4.00 Gy and higher.

In moderate acute radiation injury, we observed in the animals at marker 0.4 km a moderately expressed depression and reduction in mobility. A portion of the dogs had diarrhea. The animals' weight had decreased five to ten percent by the end of the month.

The changes in the circulating blood were characterized by a moderate reduction in the number of leukocytes in the first days, becoming more expressed by the end of the first week (down to 3-5E+9/liter). During the climax of the illness, the number of leukocytes fell to 2-3E+9/liter. A restoration in the leukocyte level up to the initial level was noted after 2 to 3 months. The changes in the differential count resulted in a reduction of the absolute number of lymphocytes and neutrophils.

By the 3rd and 4th weeks, we observed an insignificant reduction in the number of erythrocytes (by 0.5-1E+12/liter) and hemoglobin (by 1.6 to 2.5 g/dL). The sedimentation rate during the climax of the illness increased to 10 - 44 mm/hour.

As was noted above, several of the animals at this distance suffered mild radiation illness. The changes in their blood indices were less pronounced. Thus, the overall number of leukocytes by the end of the 1st week decreased from 10.3E+9/liter before the test down to 6.2E+9/liter; by the end of the 3rd week it had decreased to 2.83E+9/liter before the test.

Thus, in animals who suffered mild and moderate radiation illness, the depth of the reduction in the blood indices during the time periods was more significantly expressed than could be expected from external irradiation doses on the order of 1.50 Gy.

The dogs at the 1 km marker, with external irradiation doses of 0.38 to 0.90 Gy, developed mild radiation injury. In clinical observations, we noted a significant overall depression and reduction in mobility.

The overall number of leukocytes by the end of the 1st week was down to 4.7E+9/liter $\pm$ 0.5E+9/liter, compared to 9.9E+9/liter $\pm$ 0.7E+9/liter before the tests. By the end of the 3rd week, it was down to 5.4E+9/liter $\pm$ 0.7E+9/liter. A restoration was observed after 2 to 2.5 months. Changes in the quantitative content of leukocytes occurred mainly due to the neutrophils and the lymphocytes, where the reduction level in the absolute number of lymphocytes turned out to be more significantly expressed. Thus, if the number of neutrophils by the end of the 1st week decreased by roughly 2 times, then the number of lymphocytes decreased by 3.6 times (on the 2nd day). And later, the absolute number of lymphocytes continued to maintain itself at a lower level, and even after 3 months, they were not fully restored (on average 1.19E+9/liter versus 2.83E+9/liter before the test).

It should be noted that in animals from the 1 km marker, the level of leukopenia was also not identical. Thus, in half of the animals, the number of leukocytes decreased down to 3.1-3.2E+9/liter, or one-third of the initial values.

The depth of hematological changes in the animals at this distance corresponded to that for doses of unilateral external gamma irradiation on the order of 2.50 Gy.

It is known that when contaminated by recently formed nuclear fission products, hematological changes can have a different character depending on the quantity of radioactive material entering the body, the paths of entry, the absorption, the age of the fission products, etc. The reaction of the blood system during internal contamination from absorbed fission products (atmospheric, surface and underground nuclear explosions) differs very little from the reaction during radiation illness caused by external gamma irradiation. When contaminated by poorly absorbed by-products of surface and thermonuclear explosions, the character of the hematological changes is different. Leukopenia does not develop in such instances. Conversely, during the climax of the illness, leukocytosis is noted.

In our experience, when dogs are located in the track of the radioactive venting cloud from an underground nuclear explosion, the animals were subjected to combined effects of external beta and gamma irradiation and also internal contamination from fission products of the nuclear explosion.

The following features of radiation injury in the study animals, as compared to radiation illness caused only by external irradiation in such doses, should be noted:

- the intensity of the progression of the radiation illness does not correspond to the dose of external irradiation actually received;
- large differences in the levels of intensity of illness in different animals placed the same distance from the explosion, despite little difference in doses of external beta and gamma irradiation;
- slower restoration of hematological indices in animals who suffered from mild and moderate radiation illness.

Exacerbation of the radiation injury intensity at relatively low doses of external beta and gamma irradiation is caused by the internal contamination from fission products of the underground nuclear explosion.

DISCUSSION

An analysis of the clinical data on human injuries, as well as the results of numerous experimental investigations, indicate an indubitable dependence of the intensity of radiation injuries on the irradiation doses received. The most obvious dependencies of clinical-hematological changes on the irradiation dose values have been studied to date relative to the short-term influence of external gamma irradiation. This served as the basis to use these dependencies for a comparative evaluation of the various effects of combined radiation influences.

Level of Expression of the Initial Overall Reaction.

According to data from V.A. Ivanov (1971), A.K. Guskova and G.D. Baisogolov (1971), A.I. Vorobyov (1971), L.K. Tikhomirov (1987), and N.G. Darenskaya (1987), the degree of expression of the initial overall reaction, and the rapidity of resolution of individual symptoms, correlate rather well with the irradiation dose. The emergence of an initial reaction in the form of nausea, vomiting, headache, dizziness, general weakness and other symptoms occurs, as a rule, soon after irradiation in practically all those victims receiving doses which exceed 2.00 Gy. At lower doses, these symptoms are seen less frequently. After irradiation with a dose of less than 1.00 Gy, the overall state of the victim remains satisfactory, and no symptoms of initial reactions appear (A.K. Guskova, G.D. Baisogolov (1971).

In light of the literature data cited above, the appearance of an obvious initial reaction in a majority (roughly 80% of the cases) of those studied in groups I and II would indicate, according to the given criteria, that the integrated biological effect of combined radiation effects corresponded to an irradiation dose of not less than 1.00 Gy.

In the clinical occurrence of the initial reaction, we turned our attention to the comparatively early emergence of individual signs of a deterioration in general health. There was a significant polymorphism in the expression of symptoms which was indicative of pathological processes involving the nervous system, the hemopoietic organs, digestive organs, mucous membranes of the upper respiratory pathways, and the eyes. The period of overt symptoms was more prolonged than expected. The features noted in these subjects were not recorded in the cases of combined radiation injuries in the Marshall Islands residents (see “Hematological Changes” section). However, these features did appear in members of submarine crews during accidents in the nuclear power plants, where recently formed nuclear fission products entered into their bodies.

Clinical Emergence of Three (3) Phases of Illness.

The typical clinical picture of the peak of the illness occurred only in the test animals. It was most clearly expressed in three dogs from the first marker location (0.4 km), where the doses of general external gamma irradiation did not exceed 1.42 to 1.80 Gy. The profound clinical and hematological changes that appeared in these animals, accompanied by the appearance of ulcerous-necrotic injuries of the mucous membranes of the mouth, the emergence of hemorrhagic colitis, increased body temperature of up to 40.7 degrees centigrade, and total aplasia of the hemopoietic centers during these time periods, indicated a significant disparity from the effects normally expected from the dose of overall external gamma irradiation actually measured. According to the data in the literature, the integrated biological effects of combined radiation action, based on the severity of the clinical and hematological changes observed during the peak of the illness, corresponded to an

external gamma irradiation dose of close to 3.50 to 4.00 Gy. That is 2 to 3 times greater than the dose recorded by the dosimeter devices.

In people whose external gamma irradiation doses were 220 ± 30 mGy, there was no such illness climax. In addition, during the time period corresponding to this phase of the formation period of radiation illness (2 to 5 weeks after exposure), we discovered damage of the functioning of the nervous and cardiovascular systems, of the vision organs, as well as a moderately expressed depression of hemopoiesis and weakly expressed hemorrhagic occurrences.

According to the data from N.G. Darenskaya (1987) and A.K. Guskova and A.E. Baranov (1989), the described clinical picture and the clear phase nature of the course of the pathological processes after radiation exposure are observed only during acute radiation illness, beginning at degree II. Degree I radiation illness is characterized by the presence of only some mild symptoms, which are transient. At irradiation doses of 0.50 to 1.00 Gy, insignificant changes can arise in the blood picture, as well as weakly expressed damage in the neurovascular regulation in weeks 6 through 8 after irradiation.

Considering the cited literature data, we can assume that the effects of the exposure to individuals in Group I and II, based on the clinical manifestations seen during the 2 to 5 week period after the irradiation, corresponded to an external gamma irradiation dose of no less than 1 Gy.

Hematological Changes.

In the difficult complex of hematological processes emerging as a result of irradiation, the hematological changes are, as we know, one of the important pathogenic effects. Hemopoietic changes emerge rather rapidly after radiation exposure, and hematological investigations are accessible and simple. Because of these factors, and because of the importance of the hemopoietic system to the patient's survival, blood indices are sufficiently reliable for determining the levels of intensity of radiation injuries (N.M. Gruzdeva, 1971; A.K. Guskova and A.E. Baranov, 1989).

In some cases of our investigations, the blood picture in people and in test animals was characterized by a clear-cut phase nature in the changes, whose level of expression turned out to be somewhat greater than that which we expected at the recorded doses of external gamma irradiation. Thus, for individuals in group I, with doses of 220 ± 30 mGy, the content of leukocytes and thrombocytes decreased by roughly 30%, and the number of myelokaryocytes by 40%. In individual cases, the number of these cells decreased by more than twofold. Such changes after external irradiation were observed by I.Ia. Vasilenko (1971) at doses of from 0.80 to 1.30 Gy. The effectiveness of combined radiation action for the degree of eosinopenia and monocytopenia in the study subjects turned out to be even greater. The reduction in the content of eosinophils and monocytes of 75 and 56%, respectively, indicate a significant degree of radiation injury. In victims who lived in Hiroshima and Nagasaki, such changes occurred only with degree II radiation illness, whereas the majority of the subjects studied in group I were diagnosed with radiation reaction and only some with mild (degree I) radiation illness. The higher radiation injury susceptibility of monocytes and eosinophils, as compared to that of neutrophils, lymphocytes and thrombocytes in the group I individuals, should likely be considered a feature of combined radiation effects, since with external gamma irradiation alone such a discrepancy is not encountered, as a rule. In cases of the one-time effect of a complex of radiation factors from the cloud of a surface thermonuclear explosion for residents of the Marshall Islands, no such changes were registered, despite the higher irradiation doses (0.69 and 0.78 Gy with up to 1.5 milliCi [55.5 MBq] of radioactive material inside). (American data from Operation Castle indicated dose reconstructions of external radiation of 1.75 Gy for Rongelap, 0.69 Gy for Ailinginae, and 0.78 Gy for Rongerik; first two islands were populated by

Marshallese, Rongerik temporarily by American military personnel. Estimated body burdens on day one for Rongelap were 5.1 mCi [20 MBq] of iodine fission products and 2.743 microCi [0.1 MBq] of strontium-89, barium-140, ruthenium-103, calcium-145; estimated body burdens on day one for Rongerik were 1.8 mCi [66.6 MBq] and 0.745 microCi [27.6 kBq] respectively.--Ed.)

A valuable predictive test of the intensity of radiation injury could be the level of maximum lymphocytopenia after the effect. In individuals in groups I and II, the number of lymphocytes decreased an average of 33.1 to 36.6%. Such a level of reduction in the number of these cells was observed by American specialists in the affected Marshall Islands residents at doses of 0.69 and 0.78 Gy. In addition to this fact, the level of reduction noted in the number of lymphocytes after external gamma irradiation alone occurred at doses of 0.20 to 0.40 Gy (I.I. Sokolova, 1967). There was an almost identical reduction in the number of neutrophils and lymphocytes (roughly 30 to 35%). Despite this, the impression is created that the effect of the action on the lymphocytopenia level in group I individuals corresponded to a lower dose of external gamma irradiation when compared to the effect of the action based on the level of reduction in the number of neutrophils.

The high effectiveness of combined radiation effects while being located under a low-lying radioactive cloud is confirmed by the results of the experimental investigations. Thus, the 55% reduction in neutrophil content at doses of gamma irradiation of 0.38 to 0.90 Gy, and a 94.9% reduction at 1.42 to 1.80 Gy corresponded to a dose of external gamma irradiation alone which is two to three times greater than that registered. Roughly the same effect was obtained for lymphocyto- and thrombocytopenia, and also for changes in the hemopoietic organs of three deceased dogs. With 1.42 to 1.80 Gy doses of external gamma irradiation, these animals developed aplasia of the bone marrow, mucous membranes and lymph nodes by the end of weeks three and four.

Based on this, and also according to the hematological indices, the combined effect of radiation factors from the venting cloud of an underground nuclear explosion turned out to be three to four times more effective than single-sided external gamma irradiation for people; it was two to three times more effective for large lab animals.

The hematological changes both for individuals in group I and for test animals differed, to a known degree, from the changes in blood composition after the effect of external gamma irradiation alone in comparable doses. These differences seemed to be, mainly, the levels and duration of maximum cytopenia and duration of the repair processes. In the first 1.5 weeks, for both humans and animals with irradiation doses of 0.38 to 0.90 and 1.42 to 1.80 Gy, the rates of reduction in the content of the formed elements of the blood were relatively high. For all practical purposes they did not differ from the reduction rates of the number of cells after external gamma irradiation in injury-provoking doses. However, in the subsequent time periods, definite peculiarities arose in the reaction of the blood. So, in group I individuals, with reduction rates in the first days in neutrophil and thrombocyte numbers which corresponded to doses of greater than 1.60 Gy, the second wave of reduction in the level of these cells turned out to be significantly less pronounced. With external gamma irradiation, such a phenomenon, as a rule, is not observed (A.K. Guskova and G.D. Baisogolov, 1971). Also uncharacteristic as well for external gamma irradiation is a predominant reduction in content of monocytes and eosinophils, as compared to lymphocytes and neutrophils. For group I individuals, such a discrepancy, as was discussed above, did not occur. In addition to this, if the number of eosinophils after external gamma irradiation (in injury-provoking doses) also is reduced, then it restores itself comparatively rapidly (I.I. Sokolova, 1967). In our observation cases, the number of eosinophils did not become completely restored, even seven months after the effect. Roughly the same features in blood reaction occurred in the test animals. A profound eosinophil- and monocytopenia, and a comparatively high rate of development of neutropenia and thrombocytopenia were noted in them only at 1.42 to 1.80 Gy doses of external gamma irradiation. A less marked

depression during the second wave of depletion was noted at doses of 380 to 900 mGy. In both humans and test animals in our report, the restoration of hemopoiesis occurred significantly more slowly, as compared to the duration of repair processes after external gamma irradiation. In humans with 220 ± 30 mGy external gamma irradiation doses, the blood picture was not normalized seven months after exposure, and in animals, it was not normalized even 1.5 years after the effect.

From the complex of radiation factors, it is most likely in our opinion that internal irradiation had an aggravating effect on the level of monocyte- and eosinophilopenia, and on the long-term restoration of hemopoiesis. As far as external beta irradiation is concerned, as a rule this does not lead to a reduction in the number of these cells, but conversely, to an increase in their number, according to the data of E.A. Zherbin and A.B. Chukhlovin (1989). The relatively high rates of reduction in the level of blood cells in humans in the first 1.5 weeks after exposure may be caused by the comparatively rapid formation of dose burdens in the critical organs, the high effectiveness of short-lived radioisotopes, and the relatively more uniform distribution of radiation energy in the body. It could also be due to the intake of biologically dangerous radioactive products differing in biological accessibility.

The Role of Individual Radiation Factors of the Cloud Vented from an Underground Nuclear Explosion in Producing Injury.

When both humans and the test animals were under the radioactive cloud, they were subjected to external beta and gamma irradiation combined with internal contamination by radioactive materials. When evaluating the role of various factors in the formation of an integrated biological effect, we must consider as well the higher effectiveness of simultaneous irradiation from all sides, and, for the humans, the psycho-emotional state at the time of the irradiation.

Irradiation Geometry.

It is known that in conditions of simultaneous irradiation from all sides, the biological effectiveness of the measured dose in air in roentgens is 1.5 to 2 times higher as compared to the effect of unilateral irradiation from a point source. The noted correction coefficient was totally acceptable in the cases we observed. However, it does not completely explain the amplification of effectiveness, since the integrated biological effect in the study subjects turned out to be 3 to 4 times higher than expected for the registered doses of external gamma irradiation.

Psycho-Emotional Factor.

According to H.M. Gruzdev (1971), the emergence of symptoms of initial reaction in individuals can be caused by being psychologically and emotionally overstressed. It is completely possible that in several individuals in groups I and II, the emergence of individual symptoms could be related as well to their psycho-emotional state. However, one must keep in mind that individuals in group III (irradiation dose of 10 to 20 mGy) did not display any symptoms of an initial overall reaction, despite the fact that their psycho-emotional state at the time the explosion cloud passed by was roughly the same as for those in groups II and III. Thus, it is unlikely that this factor served to strengthen the effectiveness of the radiation action in the study subjects. It is also necessary to keep in mind that the integrated biological effect in the subjects was estimated not only according to the nature of the initial overall reaction expressed, but also with regard to several other indices, including the level of hemopoietic depression.

External Beta Irradiation.

The exacerbating effect of external beta irradiation in combined radiation effects is shown in the study by I.Ya. Vasilenko (1971). However, we saw a trend toward increasing severity of radiation illness only with the additional effect of overall external beta irradiation. In our experimental cases, the external beta irradiation of humans was predominantly local (face, neck, wrists and hands), since the test participants were wearing winter clothing at the time the explosion cloud passed by. As for the animals, they were covered by blankets, which could also have a definite protective effect.

When examining the humans, we discovered primarily conjunctivitis and only in isolated cases did we find hyperemia and edema of the facial skin. No changes in the skin of the torso or the extremities were noted. Destructive changes in the skin were also lacking in the animals from the "Telkem-1" test. [**N.B.** This was the first of a series of underground explosions of very low yield, 0.24 kt TNT equivalent, conducted in 1968, that was primarily designed to obtain parameters of mechanical and radiation effects from simultaneous underground cratering explosions. (V.A. Logachev et al., 1997)] Therefore, these data confirm that the beta irradiation doses for humans and large lab animals were relatively low. Thus, it is hardly likely that external beta irradiation could have made a significant contribution in strengthening the effectiveness of combined radiation action. It is also unlikely since in the cases of higher doses of beta irradiation in the Marshall Islands residents, no significant enhancing effect on the level of intensity of radiation injury was noted.

Internal Irradiation.

Four mCi (148 MBq) of radioactive fission products entered the bodies of humans and dogs; this could have been only via aerosol inhalation. Given this, it was established (K.I.Gordeev, 1980), that the aerosol fraction concentration of radioisotopes in inhaled air comprised 20 to 25% of the overall activity. Consequently, the total amount of radioactive materials which entered into the body could have been at maximum only roughly 20 mCi (740 MBq). According to current opinion, the minimum amount of radioactive materials up to one hour old required to cause radiation injury is 75 mCi (2.8 GBq). It is also known that we observe a more severe course of combined radiation injuries from single exposures only when there are high doses of external and internal irradiation (close to the LD_{50}).

The maximum doses of external gamma irradiation of humans (220 $\pm$ 30 mGy) and the amount of radioactive material incorporated turned out, as we saw, to be significantly less than the amounts normally required to cause radiation injury. In addition, it is hardly possible to rule out the probability of reinforcing the effectiveness of combined effects because of internal irradiation. The results of estimating the role of other factors (which was discussed above) indicated that they could have a share of about 50% of the integrated effect. It is fully possible that the remaining unexplained part of the biological effects was caused in the conditions set forth, that is by internal irradiation. Such an assumption is favored by the results of comparing the clinical and hematological changes in the test participants examined in permanent facilities to the victims residing in the Marshall Islands. With identical effectiveness of simultaneous irradiation from all sides in the groups being compared and in the lower doses of external beta irradiation in the test participants who were examined in the permanent facilities, the biological effect in the latter turned out to be the same as in the groups in Ailinginae (0.69 Gy) and in Rongerik (0.78 Gy), despite the fact that the doses of external gamma irradiation in group I individuals were 3 to 4 times less. This situation permits us to establish that when one remains under a low-lying venting cloud from an underground nuclear explosion, the role of internal contamination from radioactive materials can greatly aggravate the integrated biological

effect. According to the data from L.A. Ilyin and co-authors (1966) and G.V. Ilyin (1966), the danger from internal irradiation in such cases becomes comparable to that of external gamma irradiation.

Significant difficulties arise when one attempts to interpret the results of investigations describing acute reactions basically on the central nervous system and blood vessels of the population and of testing participants who were subjected to irradiation as a result of factors from the radioactive clouds vented from underground nuclear explosions (1965, 1974). As shown above, in both cases, the dose from acute external gamma irradiation was from 13.2 to 73.3 mGy of an overall total equivalent dose of from 115 to 177.3 mSv. Freshly produced fission products entered the body via inhaled air and via food. In the literature which was available to us, we found a sufficient amount of work which noted a rather high frequency of reactions in the nervous system to acute irradiation from external gamma radiation, and also during a later period with chronic irradiation in small doses (V.N. Doshchenko et al, 1970; A.K. Guskova et al, 1969; I.S. Glazunov et al, 1964). The authors emphasize that, as a rule, these changes have a predominantly functional character, which levels off over the course of several weeks when the irradiation dose does not exceed 0.7 to 1 Gy. Irradiation in lower doses, according to the authors' data, caused no similar reactions on the part of the nervous system.

The majority of authors (V.V. Blagoveshchenskaya, 1967; B.A. Ivanov, 1968) point out the change in the system of analyzers and the disorders of vegetative innervation. After acute irradiation in doses up to 0.8 Gy, the authors discovered a dissociated character in the changes of the taste and olfactory analyzer. In almost 63% of the study subjects, the authors recorded changes in the nervous system in the form of vegetative dysfunction with parasympathetic and sympathetic vascular reactions. We must note that, over the long term (five to ten years after the onset of irradiation), for practical purposes only sympathetic vascular reactions were recorded in the irradiated individuals, which, according to the authors, confirms the development of early post-radiation atherosclerosis.

In our investigations, during the first three days after irradiation, we discovered in the study contingents a dissociated disorder in taste and olfactory sensitivity, and a significant increase in the number of individuals with damage to parasympathetic vascular reactions as compared to the initial period ($p < 0.05$). The discovered damage leveled off in the 30 to 60 days after irradiation. As it was noted above, similar occurrences are possible at doses of external gamma irradiation not less than 0.7 to 1 Gy. Thus, we cannot directly relate the recorded changes on the part of the nervous system of examined individuals to external gamma irradiation in doses of no more than 0.18 Gy.

The second most important factor affecting the emergence of damage to nervous system and vascular reactions can be the psycho-emotional factor related to the expectation of the danger of irradiation. This factor occurred when the experiment of 15 January 1965 was conducted. The population was evacuated earlier to a safe zone; all were told that a test of some type of weapon was being prepared, and this could have created psycho-emotional stress. However, in the second case (1974), there could be no psycho-emotional stress in the study contingents, since the tests were conducted without warning the populace and there was no seismic factor involved. In this case, in the first three days, we also discovered a dissociated disorder in taste and olfactory sensitivity and a significant preponderance of parasympathetic vascular reactions in the examined individuals. We believe that, as in the case of the test personnel in 1967 subjected to acute influence of low doses of external gamma radiation (up to 0.26 Gy) and internal contamination from freshly produced fission products (up to 20 mCi, or 740 MBq), the increase in recorded effects as compared to those expected, is probably related not only to psycho-emotional stress, but also to the nature of the irradiation itself.

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